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Architecting Joint Command and Control System of Systems Capability Certifications

by

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Prepared for: Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering

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ABSTRACT

Command, Control, Communications, Computers, and Intelligence (C4I) systems, each originally designed to address a single warfighting function, have been assembled into an interdependent C4I System of Systems (SoS). The C4I SoS continues to evolve, without overarching capabilities-based performance requirements. Without requirements, there is no practical, repeatable, and objective process to assess changes to the SoS. This project applied a disciplined systems engineering process to design a Joint C4I Capability Certification Measures (JC3M) system. JC3M can be used to define performance measures for a C4I SoS, determine baseline SoS performance, assess proposed SoS changes, and monitor SoS performance. Modeling and simulation tools were used to project the performance of three existing alternatives and two new alternatives. A Life Cycle Cost Estimate (LCCE) was generated for each alternative. An Analysis of Alternatives compared performance and cost. The Joint Test and Evaluation Methodology Capability Test Methodology (JTEM CTM) was projected to provide slightly better performance than other alternatives, at the median LCCE. The results were a recommendation to monitor JTEM CTM as it completes development, and employ the JTEM CTM in a C4I SoS evaluation to confirm its estimated cost and performance.

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EXECUTIVE SUMMARY

Historically, Command, Control, Communications, Computers, and Intelligence (C4I) systems were each developed to address a single warfighting function, whether used in a single Service or as a Joint solution. C4I systems, and their use, have changed in response to advances in technology as well as the growing complexity, scope, and tempo of warfighting. Individual C4I systems, whether changed or unmodified, have been assembled by developers and the operating forces into an interdependent System of Systems (SoS) in order to achieve effects which a single system could not achieve.

The C4I SoS has grown, evolving in an almost biological manner without benefit of an overarching architecture, engineering design, or performance requirements. Without a SoS-level architecture, the effects of system-level changes on performance, capabilities, or standards compliance of the SoS are impossible to assess in an objective, repeatable, measurable, and effective manner.

Individual systems are designed, developed, tested, and fielded in response to system-level requirements. Individual systems undergo interoperability certification, which ensures compliance to standards, but does not measure SoS effectiveness. Without measures of capabilities-based performance for the C4I SoS, system-level changes have an unknown effect on the C4I SoS; the operating forces can be saddled with systems that do not work as assembled.

For example, when a Forward Observer (FO) sends a "Call For Fire," position location information, fire control systems, and communications systems are used to request artillery, rockets, or naval gunfire effects on a target. There is extensive doctrine for the conduct of fire support, but there are not documented testable values which can be used to assess the success of a Call for Fire or the C4I systems supporting the task. If a FO had to initiate a Call For Fire five times, did the C4I SoS demonstrate a successful capability to provide fire support? What if the FO had to request seven times? If a change to a component system required the FO to initiate eight times, rather than seven, is the SoS still effective? Without performance measures for the C4I SoS, accurate fielding decisions for SoS components cannot be made.

The lack of performance measures for the C4I SoS is a well-known issue, but the C4I SoS will not be completely rebuilt in order to include performance measures; there are too many legacy systems, with significant inertia, that will continue to be used. Architecting the C4I SoS as a coherent whole (design from the top down) represents an improbable shift in philosophy. The “system-centric” (bottom up) approach is likely to continue.

The Joint Capabilities Integration and Development System (JCIDS) is in place to ensure new systems are developed in response to required capabilities [CJCSI 3170.01F, 2007:2], and that those systems are "born joint." However, urgent unfunded needs statements, urgent warfighter needs, and the continued "biological growth" of the SoS make the need for a system to define performance measures an enduring one.

The purpose of this project was to develop the Joint C4I Capability Certification Measures (JC3M) system, which could define threshold performance values for the C4I SoS. A disciplined and iterative systems engineering process was applied throughout the project. Stakeholders were identified at representative C4I test organizations, Subject Matter Experts (SMEs) were consulted, and their responses were used to elicit and validate quantifiable requirements. A functional hierarchy along with non-functional requirements, complete with evaluation measures to compare the performance of alternatives, was created for JC3M, and validated through SME consultation.

Alternatives to be considered in the systems engineering process consisted of both existing systems and new conceptual systems. A review of the literature, combined with SME consultation, identified three existing systems that were potential JC3M alternative solutions. Two projects have been established recently to address the lack of performance measures for the C4I SoS. They are the Joint Test and Evaluation Methodology (JTEM) project’s Capability Test Methodology (CTM) under the Director of Operational Test and Evaluation and the Marine Air Ground Task Force (MAGTF) C4I Capability Certification Testing (MC3T) project within Marine Corps Systems Command. A third existing system, the Federation Of Systems (FEDOS) process is used by MCTSSA. Two new and unique solutions were created in order to add breadth to the comparisons.

During the design of the new alternatives, it was discovered that the initial goal of creating a system to define threshold performance values for the C4I SoS was not viable. The potential number of configurations of the C4I SoS, combined with the number of conditions in which it could be operated, created a practically infinite number of test conditions. Further, DoD doctrine [CJCSM 3500.04D, 2005, A-3] stipulated that local commanders, in response to the varied conditions their units operated in, could dictate their own performance thresholds. Any threshold performance values defined by a test organization might not be considered as representative of user needs, and thus might not be useful. These discoveries caused the reevaluation of requirements, and an associated redesign of the new alternatives. Instead of defining threshold performance values (such as “seven attempts to initiate the call for fire is an acceptable value”) the project would develop or select a system that would define what should be measured, e.g., “attempts to initiate the call for fire.” This would then lead to tests to measure these values, but leave it to the operators to decide if it met their needs.

Modeling and simulation tools were selected to evaluate the performance of the alternatives. Vitech’s CORE, Rockwell Automation's Arena and POW-ER (Project, Organization, Work for Edge Research) developed through the Virtual Design Team research at Stanford University, were used to simulate the operation of the five alternatives. CORE modeled both function and data flows; Arena quantified timing and assessed the effects of varying inputs; and POW-ER assessed processes by quantifying direct work, rework, coordination tasks, decision wait time, and worker backlog. The use of these simulation tools to complement and calibrate each other in support of systems engineering is a unique approach not found in the existing literature. Performance models were created and validated against historical data for one of the alternatives. All alternatives were modeled based on the validated model. This provided a high level of confidence in their projected performance values.

A life cycle cost model was generated for each alternative. The historical cost of one of the alternatives, based on fully-burdened labor rates and actual labor hours, was used as a baseline. A Life Cycle Cost Estimate (LCCE) was created for each alternative, which allowed comparison of overall cost, as well development, operating, and retirement cost comparisons.

An Analysis of Alternatives was conducted to compare the estimated performance of each alternative, and its associated cost, to the other alternatives. SME consultation was conducted to estimate the performance of the alternatives in some areas. SME consultation was also used to validate the functions used to convert raw performance evaluation scores into weighted performance scores for the alternatives.

A comparison of alternatives based on the modeling and simulation results indicated the JTEM CTM was projected to have slightly better performance than other considered alternatives, and had the median LCCE of the five alternatives.

The overall recommendation based on this study is to monitor the development of the JTEM CTM for further maturation as this project promises significant improvements in the overall utility of C4I SoS evaluations. The JTEM CTM was initiated in 2005; the cost for final development (2007 through 2009) is estimated at $3.5M, and will be borne by the JTEM program. The estimated operating cost, which would be borne by C4I test organizations implementing the JTEM CTM, is expected to be significantly lower than other alternatives investigated. Changes or uncertainties in performance or costs associated with the JTEM CTM will require additional analysis to confirm the expected benefits of this approach. Detailed investigation of the JTEM CTM in its entirety, and optimization of personnel resources and organizations with a modeling tool such as POW-ER, should be pursued. The JTEM CTM should also be used to conduct a C4I SoS evaluation as soon as feasible to validate methods and processes in a “real world” event.

LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

Acronym	Term
ABC	Activities-Based Costing
ACAT	Acquisition Categories
AFATDS	Advanced Field Artillery Tactical Data System
AHP	Analytical Hierarchy Process
AIRSUPREQ	Air Support Request message
AoA	Analysis of Alternatives
Arty	Artillery
ASL	Air Support List
ASR	Air Support Request
ATEC	U.S. Army Test and Evaluation Command
ATO	Air Tasking Order
BGE	Battlefield Geometry Exchange
BLT	Battalion Landing Team
Bn	Battalion
BPLI	Blue Position Location Information
Btry	Battery
C2	Command and Control
C2PC	Command and Control Personal Computer
C4I	Command, Control, Communications, Computers, and Intelligence
C4II	C4I Integration and Interoperability
C4ISR	Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance
CAS	Close Air Support
CBRN	Chemical, Biological, Radiological, Nuclear
CBS	Cost Breakdown Structure
CCA	Circuit Card Assembly
CDD	Capabilities Development Document
CDS	Compact Digital Switch
CEP	Circular Error Probable
CFF	Call For Fire
CJCSI	Chairman of the Joint Chiefs of Staff Instruction

Acronym	Term
CJCSM	Chairman of the Joint Chiefs of Staff Manual
CLC2S	Common Logistics Command and Control System
CM	Configuration Management
Co	Company
COCOM	Combatant Command
CONDOR	C2 On the Move Network, Digital Over the Horizon Relay
COP	Common Operational Picture
CPD	Capabilities Production Document
CPM	Critical Path Method
CRA	Consolidated Requirements Assessment
CST	COP Synchronization Tools
CTM	Capability Test Methodology
CTSF	Central Technical Support Facility
DISA	Defense Information Systems Agency
DMAP	Data Management and Analysis Plans
DNVT	Digital Non-secure Voice Terminal
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DoDD	Department of Defense Directive
DoDI	Department of Defense Instruction
DOT&E	Director, Operational Test and Evaluation
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
DPS	Defense Planning Scenarios
DSVT	Digital Secure Voice Terminal
DTE	Developmental Test and Evaluation
EM	Evaluation Measure
EPLRS	Enhanced Position Location Reporting System
FCB	Functional Capabilities Board
FEDOS	Federation of Systems
FO	Forward Observer
FTE	Full Time Equivalent
GCCS	Global Command and Control System

Acronym	Term
GCCS-J	Global Command and Control System-Joint
GIG	Global Information Grid
GSA	General Services Accounting
HDX	High Density Exchange
Hellfire	Helicopter Launched Fire and Forget Missile
I&S	Interoperability and Supportability
IA	Information Assurance
ICD	Initial Capabilities Document
ICEP	Interoperability Certification Evaluation Plan
ICTO	Interim Certification to Operate
IDEF	Integration Definition for Function Modeling
IGX	Gateway Exchange
INCOSE	International Council on Systems Engineering
IOS	Intelligence Operations Server
IPR	Interim Progress Review
IPT	Integrated Product Team
ISDN	Integrated Serviced Digital Network
ISP	Information Support Plan
IT	Information Technology
ITP	Interoperability Test Plan
JC3M	Joint C4I Capability Certification Measures
JCIDS	Joint Capabilities Integration and Development System
JFC	Joint Functional Concepts
JITC	Joint Interoperability Test Command
JOC	Joint Operating Concepts
JTAR	Joint Tactical Air Request
JTEM	Joint Test Evaluation Methodology
KIP	Key Interface Profile
KPP	Key Performance Parameters
LCCE	Life Cycle Cost Estimate
M&P	Methods and Processes
M&S	Modeling and Simulation
MAGTF	Marine Air Ground Task Force

Acronym	Term
MARCORSYSCOM	Marine Corps Systems Command
MC3T	MAGTF C4I Capability Certification Test
MCCDC	Marine Corps Combat Development Command
MCEB	Military Communications & Electronics Board
MCNOSC	Marine Corps Network Operations and Security Command
MCOTEA	Marine Corps Operational Test and Evaluation Activity
MCTSSA	Marine Corps Tactical Systems Support Activity
MDACT	Mounted Data Automated Communications Terminal
MEB	Marine Expeditionary Brigade
METL	Mission Essential Task Lists
MOE	Measure(s) of Effectiveness
MOP	Measure(s) of Performance
MAUT	Multi-Attribute Theory
NAWC	Naval Air Warfare Center
NCOW RM	Net-Centric Operations Warfare- Reference Model
NPS	Naval Postgraduate School
NR-KPP	Net Ready- Key Performance Parameters
NSS	National Security Systems
NSWC	Naval Surface Warfare Center
O&S	Operations and Support
OMB	Office of Management and Budget
OPLAN	Operations Plan
OPORD	Operation Orders
OPTEVFOR	U.S. Navy Operational Test and Evaluation Force
ORD	Operational Requirements Document
OSCAM	Operating and Support Cost Analysis Model
OSD	Office of Secretary of Defense
OT	Operational Test
OTA	Operational Test Agency
OTE	Operational Test and Evaluation
PEO C3T	Program Executive Office for Command, Control, and Communications Tactical
PFED	Portable Forward Entry Device

Acronym	Term
PID	Program Introduction Document
PLI	Position Location Identification
PLRS	Position Location Reporting System
PM	Program Manager
PMP	Project Management Plan
POAM	Plan of Action And Milestones
POTS	Plain Old Telephone System
POW-ER	Project, Organization, and Work for Edge Research
PRR	Problem Refinement Report
PTM	Percentage of Traceable Measures
RM	Reference Model
RWI	Radio Wireline Interface
SAR	System Anomaly Report
SAT	Self Assessment Team
SCR	System Capabilities Review
SE	System Engineering
SEDP	System Engineering Design Process
SIMILAR	State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate
SINCGARS	Single Channel Ground and Airborne Radio System
SME	Subject Matter Expert
SOC	Statement Of Capabilities
SOP	Standard Operating Procedure
SoS	System of Systems
SPAWAR	U.S. Navy Space and Naval Warfare Systems Command
SRD	System Requirements Document
SSF	Standard Scoring Functions
STA	System Threat Assessment
STE	Secure Terminal Equipment
SUT	System Under Test
SV	Systems View
T&E	Test and Evaluation

Acronym	Term
TBM	Theater Ballistic Missile
TBMCS	Theater Battle Management Core System
TEMP	Test and Evaluation Master Plan
TISP	Tailored Information Support Plan
TRITAC	Tri-service Tactical
TSP	Technical Support Plan
TST	Time Sensitive Target
UAV	Unmanned Aerial Vehicle
UJTL	Universal Joint Task List
ULCS	Unit Level Circuit Switch
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
V&V	Verification and Validation
VDT	Virtual Design Team
VMF	Variable Message Format
ZMB	Zwicky's Morphological Box

I. INTRODUCTION

A. BACKGROUND

Commanders must be able to utilize Command and Control (C2) techniques to manage the battlespace under their command. "C2 is essentially about information: getting it, judging its value, processing it into useful form, acting on it, and sharing it with others" [Joint Pub 6-02, 2006:I-2]. The tasks of gathering, judging, and processing information have been improved through the creation of Command, Control, Communication, Computers and Intelligence (C4I) systems. The intent of C4I systems is to provide commanders with the tools necessary to increase their ability to process data and increase the tempo of warfighting.

Over time, warfighting has grown in complexity, tempo, and scope; correspondingly, our military must be able to respond with increased agility across greater distances. Furthermore, warfighting will continue to change in the future, requiring our military to continually adapt and stay ahead in the rapidly shifting global environment. Lieutenant Colonel Bernd Horn, Canadian Forces, affirms this position,

> To state that the battlespace of the future – the land, air, sea, space and electromagnetic realm where armed conflict will be conducted within its cultural, economic, ecological, environmental, political, social and technological contexts – will be dramatically different from that of today is to repeat the strikingly obvious [Horn, 2003: 8].

To combat adversaries of today and tomorrow, US forces are joined not only across Services but with our international coalition partners to fight enemies as a united front. Joint C4I systems, therefore, are essential to the success of our military forces now and in the future. The US Joint Chiefs of Staff maintain "Interoperability is key to the joint force gaining information superiority in today's network enabled environment" [Joint Pub 6-02, 2006: I-8]. The interoperability of C4I systems is critical to military success.

While the need for interoperable C4I systems has long been recognized, these systems have been developed as solutions to separate problems. The services historically developed C4I systems in isolation; each system designed to address a need within one warfighting function. As the component C4I systems have developed, the ability of multiple systems to collectively achieve capabilities beyond the reach of a single system was also recognized. Systems were connected to each other, integrated with each other, and assembled in an interdependent System of Systems (SoS).

The Predator Unmanned Aerial Vehicle (UAV) was originally designed as a non-lethal high altitude reconnaissance asset [Airforce Technology, 2007]. The Helicopter Launched Fire and Forget Missile (Hellfire) was designed in the 1970s as an air-to-ground anti-armor missile to be launched from low-flying Army and Marine Corps helicopters [Boeing, 2007]. In 2000, the UAV and the missile, with separate missions, requirements, and service owners, went through a "shotgun wedding" and became an armed reconnaissance and interdiction SoS, culminating in a successful launch of a Hellfire from a Predator in 2001 [Checkpoint, 2007]. These two, formerly completely independent systems, now are linked; changes to missile weight or range, for example, must be considered in terms of effects on the payload and range of the aircraft.

After-the-fact integration is not unique to weapon systems; the C4I SoS also contains systems developed for one purpose, but now used for another. Position Location Reporting System (PLRS) was originally designed to provide friendly position location information (PLI), identification, and navigation aides. Enhanced PLRS (EPLRS) is now used by Army and Marine Corps for digital network communications. The Marines have developed C2 On the move Digital Over-the-horizon Relay (CONDOR), which uses EPLRS to extend battlefield communications via military satellite communications and provide over-the-horizon and on-the-move battlefield connectivity [Armed Forces Communications and Electronics Association, 2004]. Like the weaponization of the Predator, CONDOR integrated separately designed systems into a new SoS, and changes to components (EPLRS and military satellite communication systems) must be considered in terms of effects on the CONDOR.

CONDOR is an example of the growth, in an almost biological manner, of C4I SoS; new technology continues to be integrated with existing systems without an overarching architecture, engineering design, set of performance requirements, or managers. Without an overarching view of the SoS, the effects of system-level changes to performance, capabilities, or standards compliance on the SoS are impossible to assess in an objective, repeatable, and measurable manner.

Architecting C4I SoS upfront as a coherent whole, top down design represents a shift in this philosophy, as seen in Figure 1. However, it is improbable that the "system-centric," bottom up design, approach is likely to cease in the near future. Capabilities-based acquisition and integration requires interoperability evaluation and certification based on delivering a war-fighter capability as part of a joint SoS.

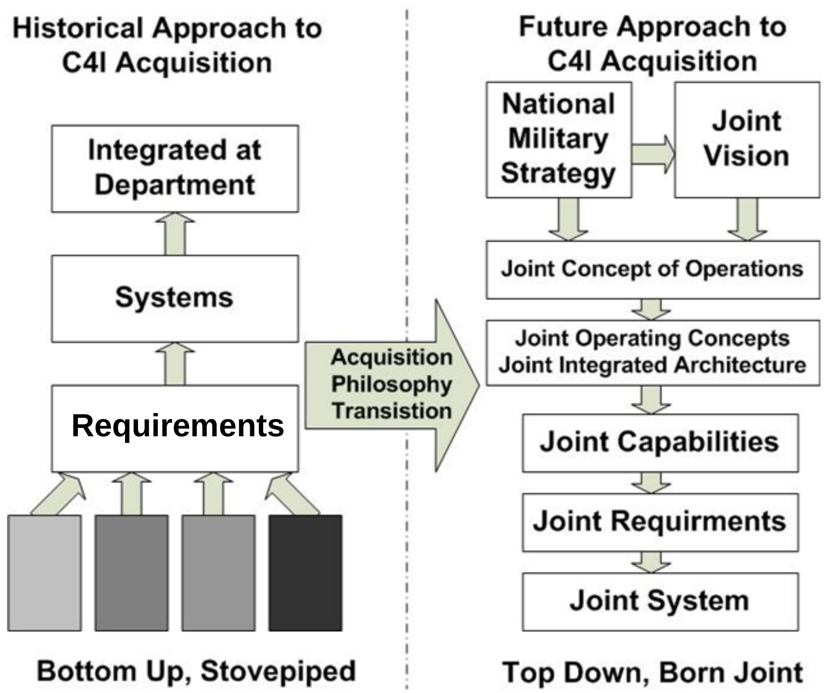

Figure 1. Transitioning Requirements Generation Philosophy

This figure represents the transitioning philosophy from stovepiped acquisition practices to acquisition of systems built from joint capabilities with the joint fighter in mind [After Hoivik, 2007: 5].

The Joint Capabilities Integration and Development System (JCIDS) process identifies "…the capabilities (and operational performance criteria) required to successfully execute missions; the shortfalls in existing weapon systems to deliver those capabilities and the associated operational risks; and the possible solution space for the capability shortfalls" [CJCSI 3170.01F, 2007:2]. JCIDS is the long term Department of Defense (DoD) answer to developing systems that are integrated and interoperable from the start.

The C4I SoS, however, continues to evolve as urgent unfunded needs statements, urgent warfighter needs, and technologies are discovered or developed. These changes are implemented as new or extended capabilities to the C4I SoS, which makes the need for a system to define performance measures an enduring one.

Congressman Jim Saxton of New Jersey, member of the Joint Economic and House Armed Service Committees, clearly agrees that problems exist with the current acquisition practices.

> Presently, the department (of Defense) allows its individual military services, agencies and field activities to determine their own IT [Information Technology] needs. This stove-piped approach has led to the confusing and complex C4ISR (Command, Control, Communication, Computers, Intelligence, Surveillance, and Recognizance) landscape that exists today. This environment has resulted in waste, redundancy and lack of interoperability in IT systems and capabilities for our warfighters [Saxton, 2003].

Today's Joint C4I SoS are required to transport and process shared data throughout the operating forces. The Joint Communication System doctrine elucidates this point.

> A joint force that is linked and synchronized in time and purpose is considered networked**.** … To do this, the communications system must be interoperable, agile, trusted, and shared. Problems are abundant because there is no baseline, standard configuration, or overall management of the SoS [Joint Pub 6-02, 2006: viii].

It is this lack of baselines, standard configurations, and overall management of SoS that make defining C4I SoS capability performance measures so difficult. Without performance measures for the C4I SoS, however, accurate fielding decisions for SoS components cannot be made. Some specific examples of the negative consequences of system-focused fielding decisions on SoS capabilities are provided in Chapter I, Section C.

C4I system-level acquisition, testing, and management are well understood, and individual systems have documented performance requirements (e.g., Capabilities Development Documents or Operational Requirements Documents). Processes and methods for designing and executing C4I system tests are well defined and executed, but testing methods at the SoS level are not well defined, nor are consistent standards and practices applied. A complicating factor is that real instances of the C4I SoS have a practically infinite number of possible configurations.

C4I SoS have ever-changing configurations that do not have formally established performance requirements, nor standard SoS capabilities that can be used to generate performance evaluation measures. There is not a clear understanding of how to manage or assess C4I SoS performance or C4I SoS capability to support joint or single Service missions.

The Joint Interoperability Test Command (JITC) is the sole DoD certification authority for joint and combined interoperability [CJCSI 6212.01D, 2007: 5]. JITC tests the interoperability of systems, but this only proves that system interfaces function. There is no agency that assesses the capability of a SoS to accomplish a task that requires the coordinated, successful integration of functions and interfaces across multiple systems. Indeed, JCIDS defines interoperability to include "both the technical exchange of information and the end-to-end operational effectiveness of that exchanged information as required for mission accomplishment" [CJCSI 3170.01F, 2007].

The goal of this project was to design a Joint C4I Capability Certification Measures (JC3M) system to fill the current capability gap that exists in the determination of a system's effect on SoS performance. JC3M is important because it is intended to provide SoS users, as well as the acquisition community, with much-needed performance requirements for the design of new systems, integration of legacy systems, and SoS testing. JC3M is also important because it will provide system integrators a tool to assess integration formally, it will document system capabilities and construction, and it will provide confidence to the warfighter that the C4I SoS works. C4I SoS have been custom built to date, with all the Configuration Management (CM), troubleshooting, training, and support challenges this "one-off" approach implies. With a consistent assessment methodology and a documented baseline configuration, C4I SoS evaluation becomes repeatable. This repeatability allows CM, training, troubleshooting, and knowledge management costs to shrink.

The JC3M team defined a system for use by C4I test organizations that will identify the desired war fighting capabilities of the C4I SoS and ensure that the system under test (SUT) meets these requirements. The JC3M system included Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) considerations in designing the system to be used by an organization, following repeatable processes, and using consistent resources.

Parallel efforts are underway to address SoS evaluation, and these approaches were considered along with other candidate solutions for JC3M. Existing efforts include the JTEM CTM, which is addressing Joint SoS performance evaluation from the Office of Secretary of Defense (OSD) level. Marine Corps Systems Command (MARCORSYSCOM), the acquisition organization for the Marine Corps, is approaching the issue from a Service perspective. MARCORSYSCOM has tasked Marine Corps Tactical Systems Support Activity (MCTSSA) to develop MC3T, a methodology for managing the MAGTF C4I SoS as a single system, in accord with modern systems engineering practices. MC3T will manage the MAGTF C4I SoS as a set of SoS-level capabilities, rather than as a fixed hardware or software baseline.

JC3M leveraged MC3T and JTEM efforts, cooperating and consulting with both organizations as stakeholders. Individual JC3M team members will work with both JTEM and MC3T as their processes mature and are implemented. JTEM is expected to complete development in 2009; MC3T is conducting a proof of concept event from October through December 2007.

B. PROBLEM STATEMENT

Information Age C4I systems have grown biologically into an interdependent entity, a System of Systems. There is no clear consensus on how to evaluate a C4I SoS capability, that is, a task only achievable by interdependent multiple components. Current inter-operability certification processes only partially address SoS end-to-end evaluation; systems are certified and delivered with interfaces functioning from a technical perspective but with less than optimum results or end-user dissatisfaction from an operational effectiveness standpoint. Capabilities-based acquisition requires interoperability evaluation and certification based on delivering a war-fighter capability in an operational environment as part of the SoS. The primitive need, as identified by the MC3T team lead, was for testable threshold values to use in the design and conduct of a C4I SoS test. This statement is based on experience at MCTSSA in conducting SoS tests for acquisition agencies. This led the team to the problem statement below:

> There is no system that defines and compares System of Systems performance measures to warfighter needs in an objective and measurable way [Finn, 2007].

C. OPERATING FORCES NEED FOR JC3M

The lack of SoS-level performance measures is not an issue that only affects the test community; there are consequences to the operating forces as well. Two examples of system-level changes which were tested and fielded without SoS-level performance measurements are provided. The test cases are summarized below.

1. Example 1 – Voice Switch Fielding

The first example, testing and fielding of voice switches, affected operating forces communication networks. This problem involves three different voice switches fielded over eighteen years for the Marine Corps. A voice switch is a system of electronic components that connects telephone calls, providing voice communications between calling and called subscribers. When placing a telephone call, the person initiating the communications is a calling subscriber and person receiving the communications is a called subscriber. When a calling subscriber makes a phone call to a called subscriber, the calling subscriber hears a ring back tone (ring … ring, in the ear piece) and the called subscriber's phone physically rings. The called subscriber picks up the phone and the voice communication path is established. This communication capability is made available through the use of voice switches.

The Unit Level Circuit Switch (ULCS), Integrated Serviced Digital Network (ISDN) Gateway Exchange (IGX), and Compact Digital Switch (CDS) are switches interoperated through trunks which provide voice paths between two switches. Three different types of telephones were involved: Secure Terminal Equipment (STE) in Plain Old Telephone System (POTS) mode for non secure calls, Digital Secure Voice Terminal (DSVT) for secure calls and Digital Non-secure Voice Terminal (DNVT) for non secure calls. The STE was connected to IGX; the DSVT and DNVT phones were connected to the CDS and ULCS

Each voice switch is similar, and provides secure and non secure voice communication capabilities. CDS and ULCS switches are designed and built to the tri-service tactical (TRITAC) communication specifications. The IGX was required to interface with both the CDS and ULCS by implementing a specification the same as the TRITAC specification. The architecture can be configured in many ways forming the SoS that provides a voice communication capability

Testing was conducted and a voice call was successfully completed between IGX and CDS using a non secure telephone. The conclusion was that the IGX and CDS worked according to the system-level specifications. Voice calls were successfully completed between CDS and ULCS using all three different telephones. The conclusion was that CDS and ULCS worked according to the system-level specifications. After testing, the systems were fielded.

After fielding, the operating forces implemented an architecture using all three switches connected in series; the IGX was connected to the CDS, which was in turn connected to the ULCS. Users found a call could not be successfully completed from a non secure phone from the IGX through the CDS to a DNVT called subscriber at ULCS switch. The called subscriber DNVT rang but the calling subscriber’s non secure phone did not get a ring back tone. The interoperability and specifications had been tested, and all three systems passed. The problem was that the architecture that supported the capability, as implemented by the user, was not tested. As a result, these switches were fielded, and it was only after delivery to the operating forces that this failure was observed. This failure continues to this day, forcing workarounds for communicators, and limiting their use of voice switches in all configurations.

The JC3M system would have identified the SoS architecture(s) that provide the capability, including viable configurations, tested those configurations, and ensured the configuration was documented for use by the operating forces. Without JC3M, however, these switches were fielded and the operating forces discovered after fielding specific configurations did not work.

2. Example 2 – Gateway Exchange Interoperability

The second example, gateway exchange interoperability, also affected operating forces communication networks. The ISDN IGX and High Density Exchange (HDX) are voice switches with a Radio Wireline Interface (RWI) Circuit Card Assembly (CCA) that provides interface capability with radios. Single Channel Ground to Air Radio System (SINCGARS) radios provide wireless voice communications. IGX , HDX and SINCGARS are assembled as a SoS to provide voice communications capability to subscribers through voice switches and radio operators.

There were three different versions of software used in the IGX and HDX, and testing was performed on all three versions. The configuration of the SINCGARS and RWI CCA did not change.

The version interoperability between IGX version 6.0a and SINCGARS radio was successful, but IGX version 6.1a and HDX version 1.0a were not successful. When versions 6.1a and HDX 1.0a were developed, they were not tested with the RWI CCA.

The JC3M system would have identified the SoS architecture(s) that provides the capability, to include the legacy system hardware, the RWI CCA, with HDX. During SoS testing, the interoperability problem between voice switches and SINCGARS radios would have been identified and fixed, before it was fielded. Although the RWI CCA is at the end of its life cycle, it is part of HDX, the latest voice switch. Had there been a JC3M system, there would have been a documented requirement for RWI interface with IGX and HDX prior to testing

D. THE SYSTEMS ENGINEERING DESIGN PROCESS

1. Overview

The team implemented a Systems Engineering (SE) approach that started with the identification of customers' needs and proceeds through the phases illustrated in Figure 2 until a recommended solution was generated. Each phase was broken down into one or more subtasks that break the larger phases into elements. At the end of each phase the opportunity to re-evaluate progress and return to a prior stage for refinements was available if necessary. This refinement process was critical to adapting the project to ensure the customers' and stakeholders' needs are achieved. The SE process model below was based on a combination of System Engineering Design Process (SEDP) [Paulo (a), 2005] and State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate (SIMILAR), modified and combined to fit this project.

The SE process presented in Figure 2 is slightly different than the original SE process provided within the Project Management Plan (PMP) (Appendix A). In the original SE process, the Modeling phase composed a single phase and the Simulation and Analysis of Alternatives (AoA) elements were joined in the next phase. Through the implementation of the SE process, the team realized that this did not truly represent the phases as they were logically and physically executed. Therefore, the simulation element was moved to the modeling phase. The result is a phase boundary change, and not a reorganization of the SE process.

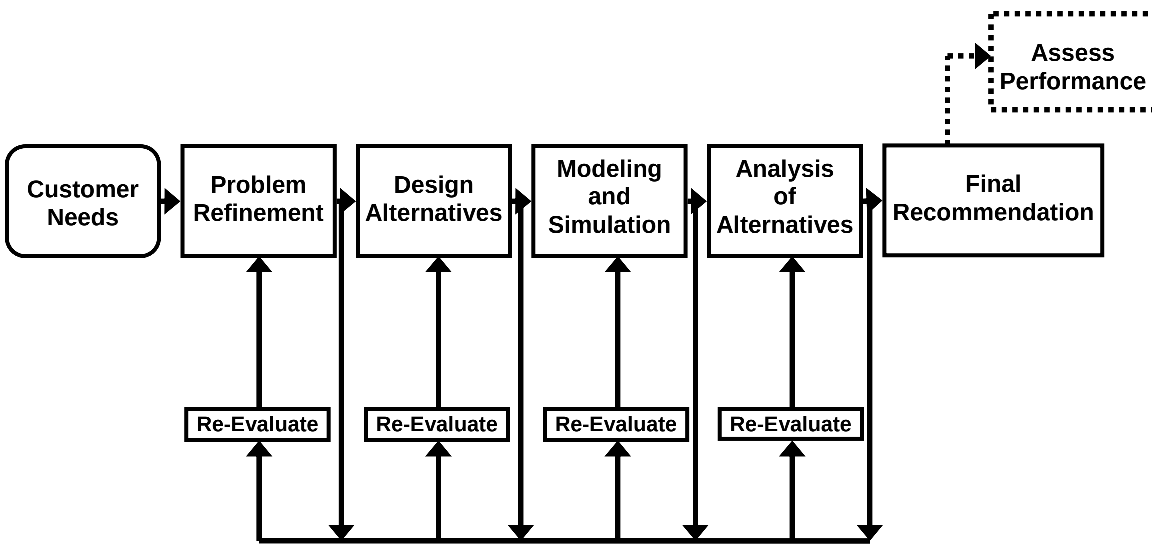

Figure 2. JC3M Systems Engineering Process.

This SE process model is based on combination of SEDP by Professor Paulo and SIMILAR System Engineering Process Model from INCOSE. Central to the JC3M Systems Engineering Process is the ability to re-evaluate after each element to update or rework an element as required prior to moving on.

2. JC3M Systems Engineering Process Phases

Each of the JC3M Systems Engineering process phases is briefly described to provide a summary of the SE process the team utilized throughout this project. Each phase and the associated elements are described in greater detail within Appendix A.

a. Problem Refinement Phase

The team utilized the Problem Refinement phase to clarify stakeholders' needs and begin managing the JC3M project risks. The outputs of this phase allowed the team to design multiple solutions for the JC3M system problem. The Problem Refinement Phase is composed of three key elements: Needs Analysis, Requirements Generation and Analysis, and Values System Design, which includes definition of Evaluation Measures (EM). Each element and the associated inputs and outputs are provided in Figure 3. It was also during the Problem Refinement phase that the team initialized risk management techniques.

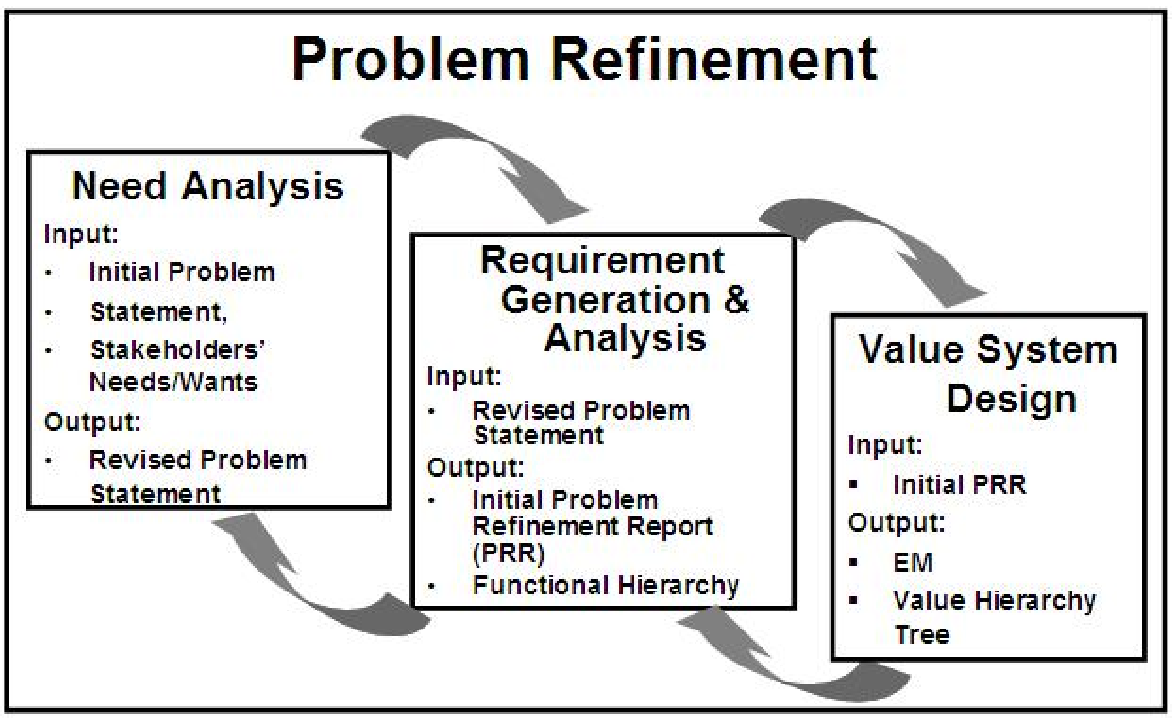

Figure 3. JC3M Problem Refinement Phase.

The Problem Refinement Phase consists of three key elements, each providing outputs for later phases and elements. Central to the JC3M Systems Engineering Process is the ability to re-evaluate after each element to update or rework an element as required prior to moving on.

b. *Design Alternatives Phase*

The team utilized the Design Alternatives phase to generate multiple candidate solutions to the problem, establish feasibility criteria and apply those criteria to eliminate those alternatives that were clearly infeasible. The creation of these solutions required the outputs of the Problem Refinement phase. The outputs of this phase were used for the creation of models in the Modeling and Simulation phase. The Design Alternatives Phase is composed of the three key elements: Alternatives Generation, Feasibility Criteria, and Alternative Scoring. Each element and the associated inputs and outputs are provided in Figure 4.

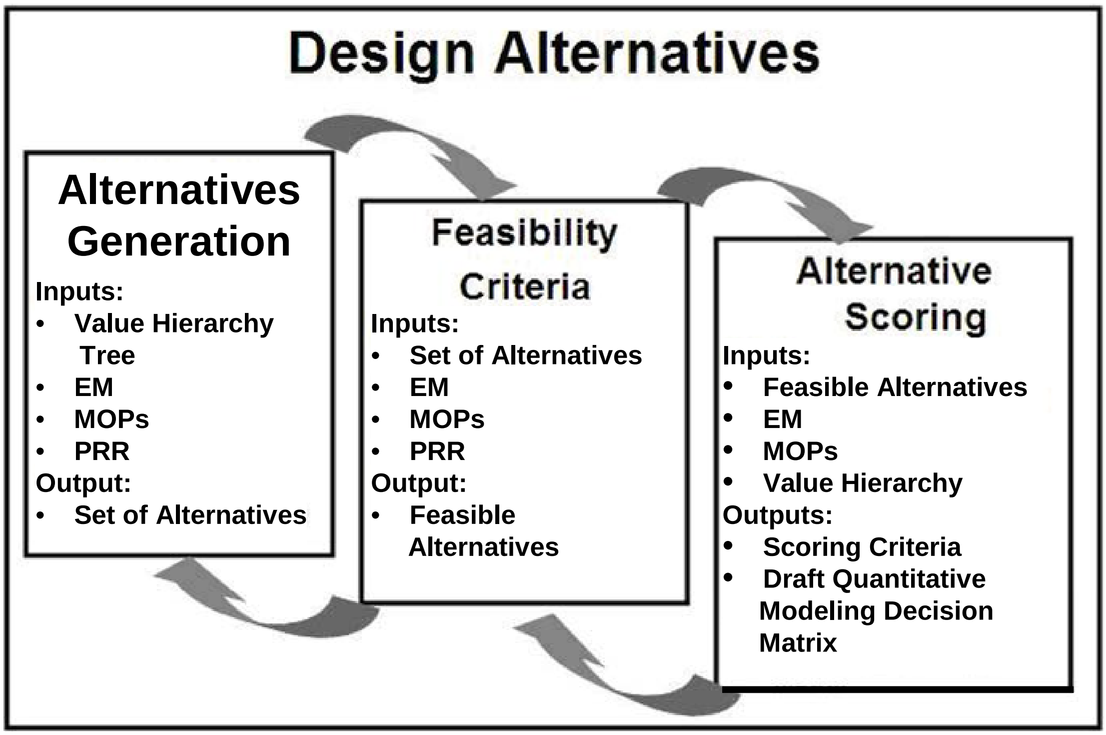

Figure 4. JC3M Design Alternatives Phase.

The Design Alternatives phase consists of three key elements, each providing outputs for later phases and elements.

c. Modeling and Simulation Phase

The team utilized the Modeling and Simulation phase to generate models based on the alternatives selected in the Design Alternatives phase. Once the models were built, the alternatives were simulated to provide results for comparison in the AoA phase. The Modeling and Simulation phase is composed of the two key elements: Model Development and Simulation. Each element and the associated inputs and outputs are provided in Figure 5.

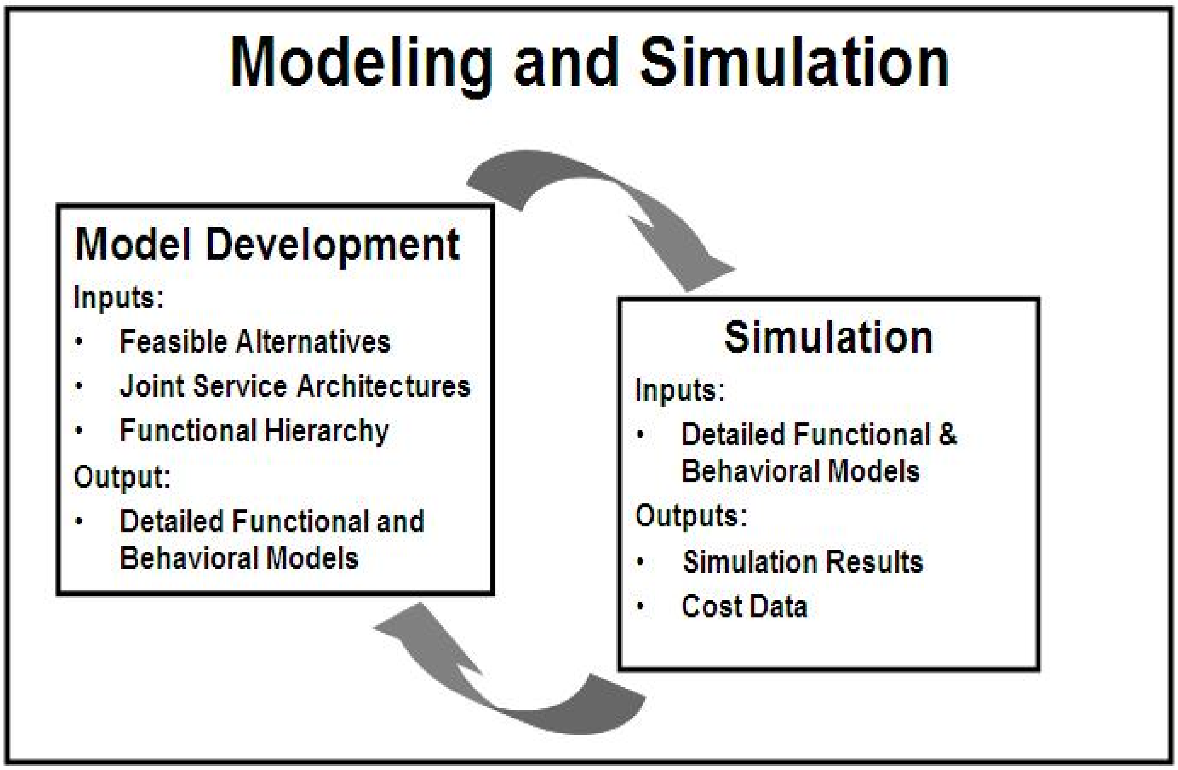

Figure 5. JC3M Modeling and Simulation Phase.

The Modeling and Simulation phase consists of two key elements, each providing outputs for later phases and elements.

d. Analysis of Alternatives Phase

The team utilized the Analysis of Alternative phase to examine each alternative's cost in light of its performance that resulted from the Modeling and Simulation phase. Multi-attribute value modeling techniques were employed to evaluate and rank each of the alternatives. The output of this phase provided utility scores and life cycle cost estimates for each alternative to the Final Recommendation phase for decision making. The Analysis of Alternatives Phase is composed of the two key elements: Cost Analysis and Multi-attribute Value Modeling. Each element and the associated inputs and outputs are provided in Figure 6.

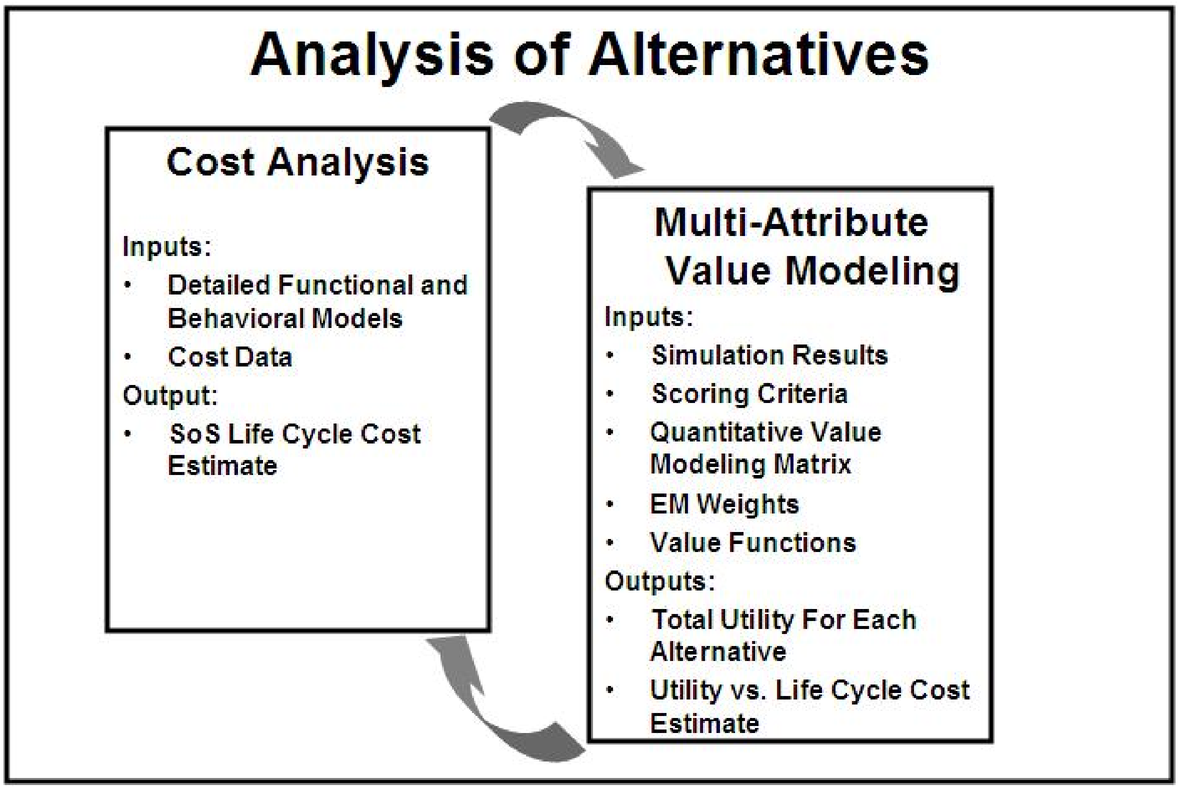

Figure 6. JC3M Analysis of Alternatives Phase.

The Analysis of Alternatives phase consists of two key elements, each providing outputs for later phases and elements.

e. Final Recommendation Phase

The team utilized the Final Recommendation phase to assemble all earlier inputs, leading to a preferred alternative and a cohesive recommendation for implementation, which is published in this final report. The output of the Final Recommendation Phase will be provided to both the JTEM and MC3T teams for their use. The MC3T implementation team is a critical stakeholder, but their schedule includes a proof of concept event in October 2007. Based on this schedule, the MC3T team concluded they could not wait for JC3M project outputs. MC3T implemented an interim process, and will review the JC3M project report for inclusion of applicable recommendations as MC3T refines their processes. The Final Recommendation Phase is composed of one key element: Recommendation. The element and the associated inputs and outputs are provided in Figure 7.

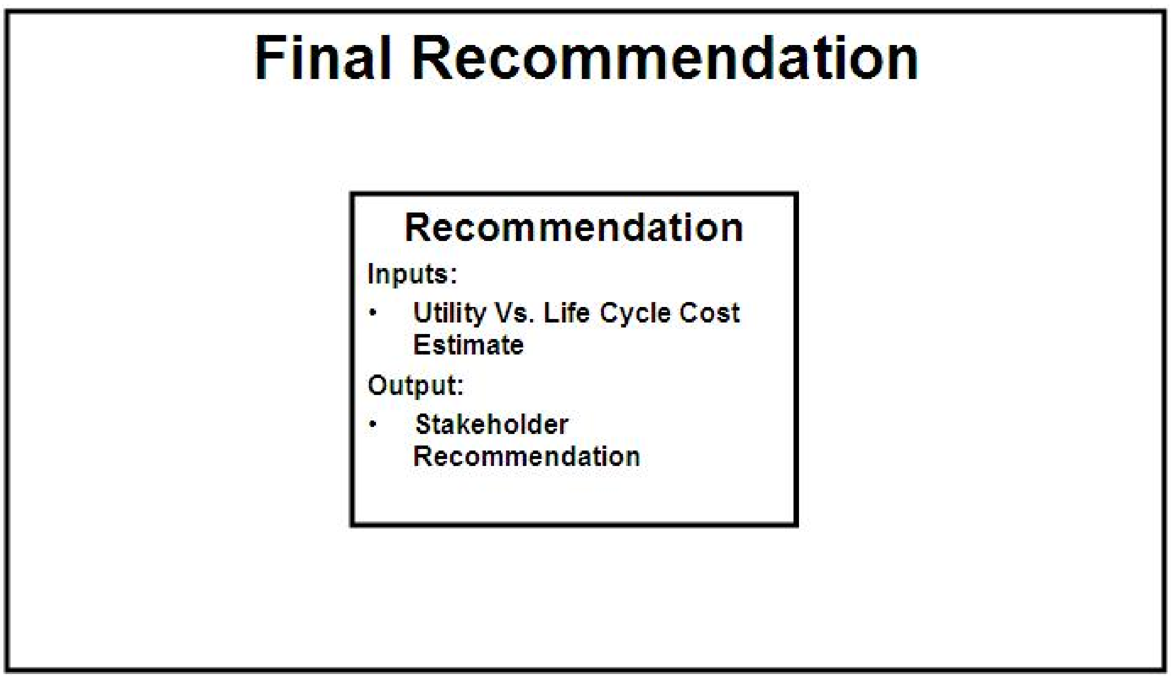

Figure 7. JC3M Final Recommendation Phase.

The Final Recommendation phase consists of one key element. This phase is the culmination of all the prior phases and provides the recommendation to the stakeholders for concurrence.

f. Assess Performance Phase

This project does not completely conclude after delivery of the final report. Some members of the team will continue to work with MC3T, JTEM, and other stakeholders after this project concludes. Some members of the team already participate in the JTEM Capability Testing Community of Interest, where they will share their experiences with other members and continue to advance the art of capability testing.

II. PROBLEM REFINEMENT

Problem Refinement was the stage of the JC3M process that refined the initial understanding of the problem into a workable system design. The JC3M SE process, discussed in Chapter I, was used in an iterative manner both to direct the process of developing a solution, as well as to guide the team away from immediately designing the JC3M solution before all the requirements were understood. Each stage of the SE process was iterative; each phase and element presented the opportunity to re-evaluate progress and return to a prior stage for refinement if necessary. While this presented a challenge in managing the growth of the project ("scope creep"), it was also critical to adapting the project to ensure the needs of the stakeholders as identified in this Chapter were met.

To accomplish the transformation from perceived need to documented requirements, the SEDP [Paulo (a), 2005] calls for Stakeholder Analysis, Input-Output Modeling, and Functional Decomposition. The JC3M team blended the SEDP methodology with a modified customer requirements capture process [Stevens et al., 1998: 28] and separately collected user and system requirements, organized the requirements, and created requirements documentation.

Problem Refinement consisted of three tasks: Needs Analysis, Requirement Generation and Analysis, and Value System Design. Needs Analysis task identified stakeholders relevant to the problem. While some [Whitten and Bentley, 2007:7; Stevens et al, 1998:21] define stakeholders as only persons, the JC3M team chose to include selected organizations as stakeholders because the duration of organizations and the missions those organizations perform outlast individuals. MCTSSA has been testing C2 software since 1972, yet none of the original MCTSSA personnel remain at the organization.

The Needs Analysis portion of the SEDP conducted an investigation of the problem, in order to refine the problem from a primitive need to an effective need, and deliver a refined problem statement. Needs Analysis also served as a control gate, which rendered a go or no-go decision for continuation of the design process. If the Revised Problem Statement, the primary output of Needs Analysis, had revealed the effective need was already met, thus stopping the design process, the JC3M team would have undertaken a different project. Because the Refined Problem Statement showed an effective need existed, it provided justification to continue further with the design process.

Requirements Generation and Analysis took the Refined Problem Statement and performed system decomposition to clarify requirements. Those requirements were decomposed into critical functions and functional flows. The outputs of Requirements Generation and Analysis were the Problem Refinement Report and the JC3M Functional and Value Hierarchies.

Value System Design took the Problem Refinement Report and Functional Hierarchy and identified characteristics and measurable parameters of the JC3M system, which were used later to evaluate alternative solutions. Outputs of Value System Design were Evaluation Measures (EM) as well as the JC3M values and functions, documented in the JC3M Value Hierarchy

A. NEEDS ANALYSIS

Needs Analysis consists of identifying stakeholders and their requirements [Verma, 2006]. The functional need identified by stakeholders was translated into qualitative and quantitative requirements later in the JC3M design process.

1. Stakeholder Identification

Key stakeholders must be identified in order to determine their requirements. Whitten and Bentley [2007] and Stevens [1998] described the need for stakeholder input, but assumed stakeholders were identified. Verma [2006: 8] stipulates that stakeholders can be active or passive, yet does not explain how internal or external stakeholders can be identified. Identification of the people and organizations that were to become JC3M stakeholders was critical, so the team used several methods in this stage.

First, the team created a list of potential stakeholders. An internal review of the team confirmed a substantial experience base in C4I SoS testing in general, current test processes, and the development of new test processes. Team members were experienced in hardware and systems testing; systems development and testing; C4I SoS testing; and the development of new test methodologies. This experience base was polled, and a list of potential stakeholder organizations was created:

- Joint Interoperability Test Command, Ft. Huachuca, AZ
- Marine Corps Operational Test and Evaluation Activity (MCOTEA), Quantico, VA
- U.S. Army Test and Evaluation Command, Alexandria, VA
- U.S. Navy Operational Test and Evaluation Force, Norfolk, VA
- U.S. Air Force Operational Test and Evaluation Center, Kirtland AFB, NM
- MCTSSA, Camp Pendleton, CA
- U.S. Army Program Executive Office for Command, Control, and Communications Tactical (PEO C3T)

As the project continued, some members were assigned, as part of their normal, non-academic duties, to investigate and develop a new test methodology (see Chapter III, Section A.1. Known Alternatives – MC3T). As part of this effort, external to JC3M, the team was introduced to the JTEM Capability Test Methodology (CTM) process. The JTEM CTM team proved to be a very valuable participant in defining requirements, validating key JC3M concepts and service, and an alternative JC3M solution (see Chapter III section A.1 Known Alternatives – JTEM CTM for details).

The team refined the list of potential stakeholders, targeting organizations that were interested, willing to participate, and representative of a portion of the C4I test community. The team identified organizations that provide service-specific test perspective on current test challenges (MCTSSA, PEO C3T); DoD-level perspective on current and future test developments (JITC, JTEM CTM); and academic and theoretical perspective (NPS). The key stakeholders that were consulted throughout the duration of the project were: JITC, MCTSSA, JTEM CTM, PEO C3T, and NPS.

2. Stakeholder Initial Requirements

As stakeholders were identified, perceived needs were reviewed and documented in an initial problem statement. The primitive need was for testable threshold values to be used in the design and conduct of a C4I SoS test. While Finn [2007] defined what he perceived as the effective need, a system to evaluate SoS performance, Bjorkman [(a),2007] agreed with the team that the definition of test criteria is a central challenge in SoS testing. SoS complexity and test challenges are not limited to DoD, but in the interests of managing the scope of the project, the JC3M team will focus on DoD C4I SoS.

B. REQUIREMENTS GENERATION AND ANALYSIS

Requirement Generation and Analysis was another critical stage in the design process, because it further clarified requirements, identified critical functions of the system, and documented those requirements for use in all later stages.

1. Requirements Identification

The goal of requirements identification was to move from the primitive need expressed above to a more refined, more accurate effective need. The primitive need is reflective of the stakeholder's bias, experience, and perceptions [Paulo (c), 2005:1] so the JC3M team explored this perceived need, and looked at the larger context of the problem, to find the true, underlying (effective) need.

The transition from primitive need to effective need was based on stakeholder inputs that were captured via stakeholder focused interviews and were aided by questionnaires. After reviewing the primitive need, the JC3M team generated a questionnaire to solicit comments, perspective, and specific guidance from potential stakeholders. The questionnaire was reviewed verbally or provided for review electronically. The questionnaire and responses are provided as Appendix B. Respondents include:

- JTEM: verbally reviewed with Dr. Dave Dryer and Mr. Tim Beach on 14 February 2007
- MC3T: reviewed in person with Mr. Ian Finn on 23 February 2007.
- Central Technical Support Facility (CTSF): provided in February 2007. Comments not released.
- JITC: questionnaire provided in February 2007. Comments received 28 Feb 2007

The initial version was formulated to capture SoS information, but did not capture information necessary to refine JC3M requirements. The revised questionnaire was submitted to JITC, and their response is also included in Appendix B. In their response, JITC Subject Matter Experts (SMEs) provided detailed guidance on overarching interoperability and integration requirements, DoD mandated events and processes, and their role in standards conformance and interoperability testing. This information was central to the development of the two new alternative solutions for JC3M. The JITC responses also cemented the developing relationship between JITC and the team. JITC SMEs were consulted throughout the project, participated in both of the project formal reviews, and assisted with the validation of requirements and approaches.

2. Requirements Analysis

Neither interviews with stakeholders nor internal team reviews could identify a system to satisfy the primitive need as articulated by Finn [2007]. The team determined the effective need was for a system that could define threshold performance values for the C4I SoS. These threshold performance values could be used, in turn, by existing SoS test systems to evaluate SoS performance. Internal and external reviews, as well as a search of the existing literature, showed there was not a system in place to meet the effective need.

As a solution to this problem, the JC3M system was to be designed to meet the effective need in the planning, conduct, and reporting of C4I SoS performance. Note that existing Joint or Service valid processes were used where applicable; the JC3M system does not, for example, define how to conduct a stakeholder meeting, define the creation of test scripts, or define how to communicate test results to stakeholders. Because the conduct of assessments is well-understood and executed by C4I test organizations, as is reporting the results of those assessments, the JC3M system is focused on the steps leading up to and including planning of an assessment.

The functional analysis of JC3M requirements was conducted by the JC3M team, and the model was validated in discussions with Mr. Ian Finn, MC3T test lead at MCTSSA, as well as at JC3M Program Reviews (16 March 2007, 08 June 2007). Attendees included representatives from JITC, MCTSSA, PEO C3T, and JTEM. This model was subsequently expanded by the team to develop the value systems hierarchy (see Chapter II section C, Value Systems Design). The hierarchy of JC3M was constructed based on three major functions in the evaluation of a C4I SoS. The first function, Planning the C4I SoS Evaluation, was the focus of JC3M. The second function, Conducting the C4I SoS Evaluation, as well as the third function, Reporting the Results of the C4I SoS Evaluation, are not modeled, for reasons stated above.

From the Plan function, the JC3M team decomposed sub-functions (Define Problem, Identify Systems, Define Criteria and Plan Review). This analysis identified planned inputs and outputs from each function and sub-function. Figure 8 illustrates the major functions of JC3M.

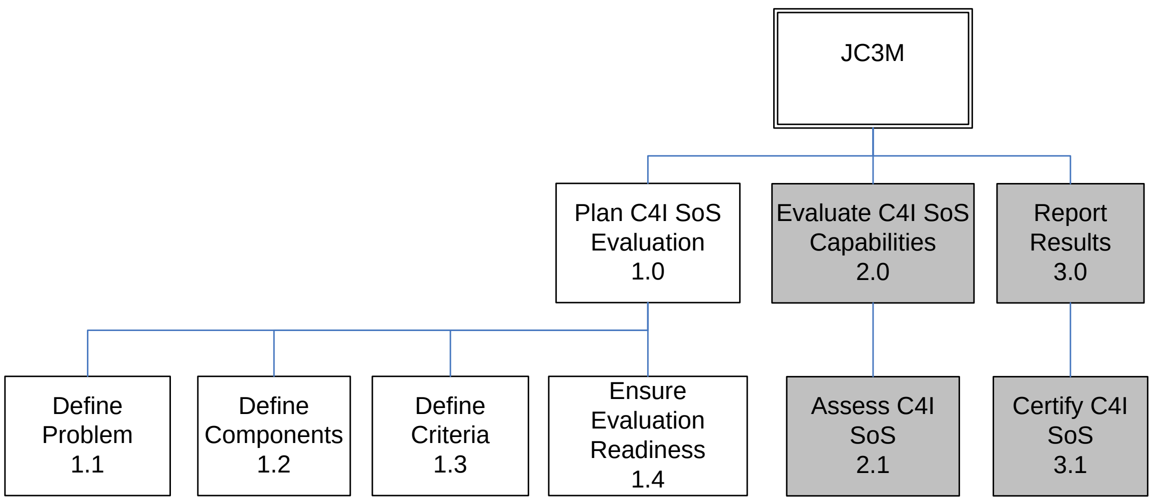

Figure 8. JC3M Functions.

Development of JC3M focused on Planning a C4I SoS Evaluation. This figure illustrates the decomposition of subfunctions within the JC3M Planning Process. Conducting a C4I SoS evaluation (2.0) and Reporting the Results of the Evaluation (3.0) were recognized as well-functioning processes at C4I test organizations; JC3M proposed utilization of these existing processes, rather than developing new processes.

3. JC3M Inputs and Outputs

Inputs to the JC3M system include stakeholder requirements, C4I SoS components, and labor. Outputs of the JC3M system include the assessment plan for the C4I SoS and capabilities under review; EM; and a SE Artifact report, which describes the current state of requirements documentation for the SoS and components under review. One of the secondary outputs includes a documented C4I SoS configuration with documented capabilities, which in turn can provide war-fighters with a known baseline configuration for implementation. If utilized, this baseline increases war-fighter confidence in the effectiveness of the C4I SoS, and reduces the resources required for C4I SoS implementation, use of the SoS, training, troubleshooting, and life cycle support. While the assessment plan is a by-product, the directive portion of the assessment plan ("in order to assess the capability to perform Task X. . . the System Y operator will initiate a request for support by sending message 1 via function 2 from screen 3. . . ") can be used as a "how-to" list for SoS operators.

C. VALUE SYSTEM DESIGN

Value System Design was the process used to create a qualitative and quantitative model [Paulo (c), 2005] which portrayed the system functions, objectives, and evaluation measures. The quantitative model was used to analyze and evaluate the performance of the alternative solutions. Value System Design was conducted by Value System Modeling and creating a Value Hierarchy.

The project team found the description ". . . developing a good set of MOEs [Measures of Effectiveness] is usually a harrowing business" [Feuchter, 2000: 40] an accurate account of the process.

1. Value System Modeling

The value system of JC3M system was constructed based on a three-phase model of C4I SoS performance evaluation: Plan the execution of the evaluation, Conduct the evaluation, and Report on the evaluation. This model was constructed based on JC3M team experience with C4I SoS evaluation.

From the top-level functions (Plan, Conduct, Report) the JC3M team identified sub-functions, and an objective was identified for each of the sub-functions. After objectives were established, each was reviewed to determine an appropriate level of performance which was used in comparing the alternative solutions [Feuchter, 2000: 39-40]. The overall goal was to be able to drill down from effective need for JC3M, to get to the "what" that JC3M was designed to do, and eventually to the "how well" standards of performance. As seen in Figure 9, Feuchter calls the "how well" factors MOE; the JC3M team refers to these as EM.

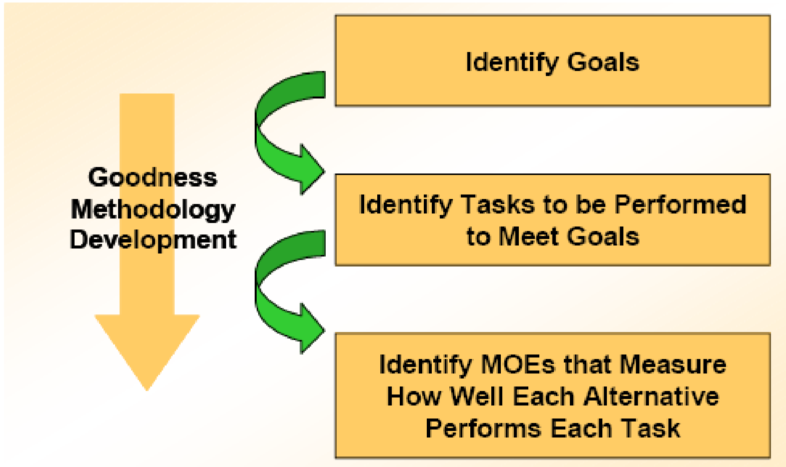

Figure 9. Developing Evaluation Measures

Evaluation Measures Trace Back to System Goals. The complete Value System Model process and results are included in Appendix E. Most EM have a single quantifiable factor, but some have multiple factors. A graphical layout of the Value System Hierarchy is also included as Appendix E [From Feuchter, 2000:40].

2. Value Hierarchy

The JC3M team determined functional analysis [Blanchard and Fabrycky, 1998: 26] was required to ensure stakeholder requirements were incorporated in the final JC3M system. Stakeholder requirements were collected (Appendix C – Questionnaires), and a value hierarchy [Paulo (b), 2005] was created to translate stakeholder requirements into design criteria [Blanchard and Fabrycky, 1998: 29] for the JC3M system. The initial decomposition of system requirements is displayed in Figure 10.

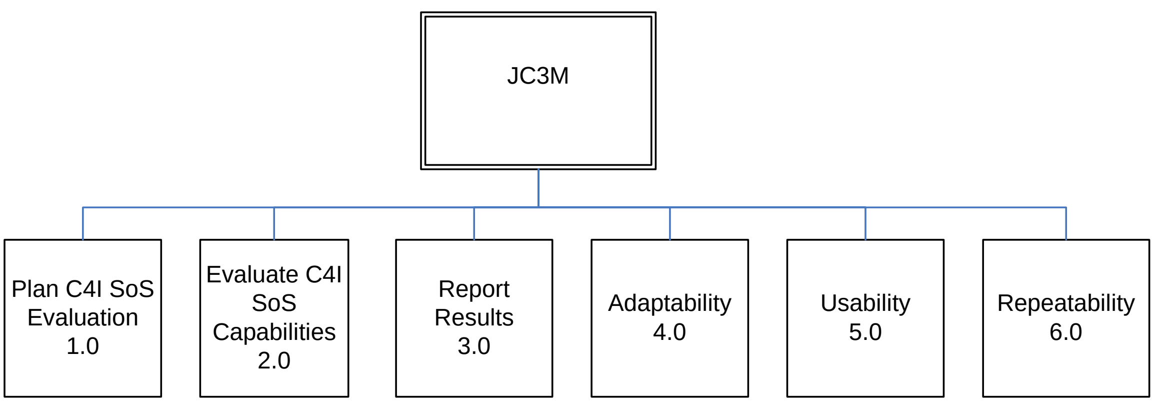

Figure 10. JC3M Top Level Value Hierarchy.

Top level value hierarchy for the JC3M system after stakeholder input. As described, JC3M will focus on the functional requirements in section 1.0, and utilize existing processes and methodologies for 2.0 and 3.0.

The team developed the value hierarchy with both functional (1.0, 2.0, 3.0) requirements and non-functional (4.0, 5.0, and 6.0) requirements [Buede, 2000: 39]. From this initial level of requirements, more discrete sub-functions were identified by reviewing stakeholder expressed and implied requirements. The complete JC3M value hierarchy and all measures are provided at Appendix E. Figure 11 shows the critical measures in white boxes.

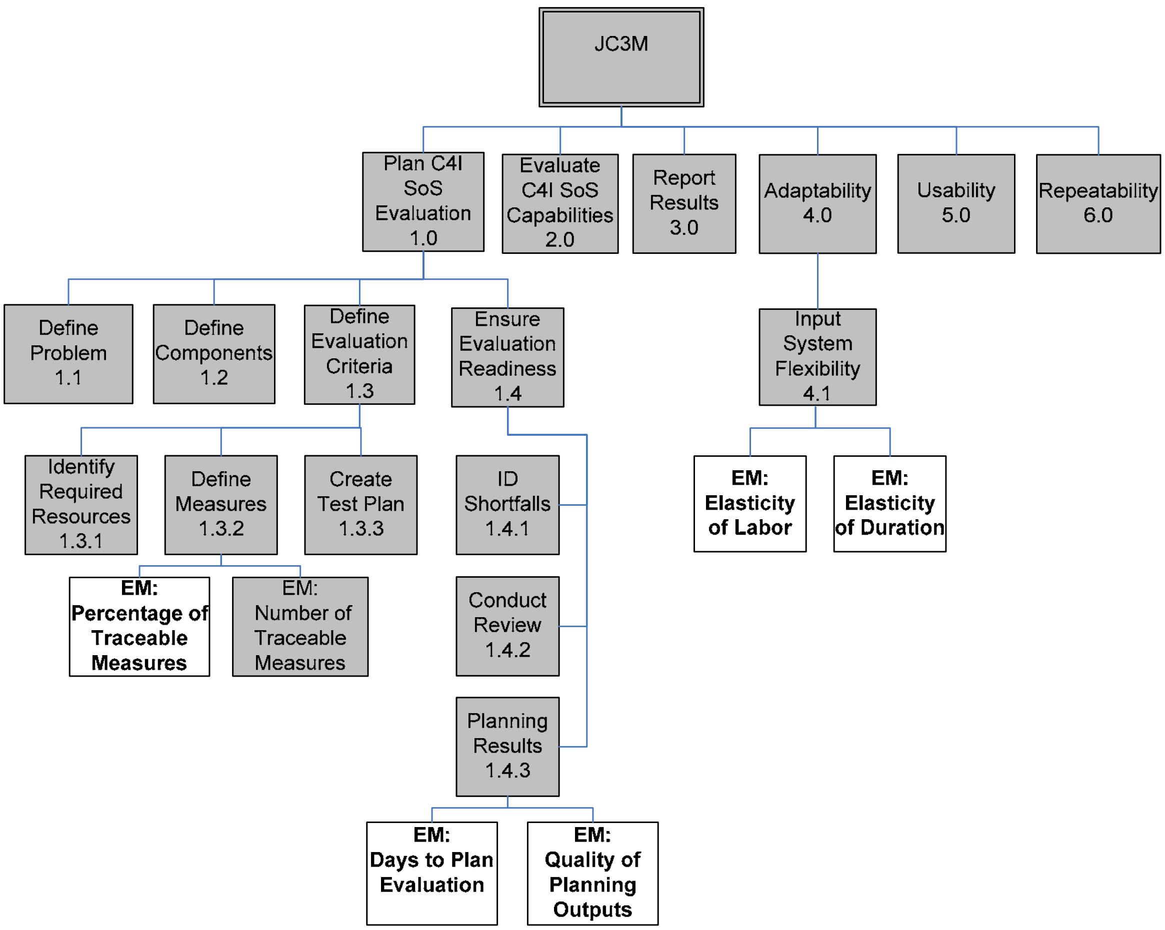

Figure 11. JC3M Functional Hierarchy.

This figure illustrates selected JC3M subfunctions based on the JC3M Value Hierarchy (illustrated Figure 10). Figure 11 also illustrates the traceability of EM to JC3M functional and non-functional requirements.

3. Critical Evaluation Measures

EM were developed for each function of the JC3M system, to ensure each function was not only measurable, but potentially capable of serving as a discriminator in considering alternative JC3M solutions. This section provides a summary of the critical EM to be used in analyzing JC3M alternative solutions. A detailed description of all JC3M EM is provided in Appendix E

Table 1 identifies the critical EM used to compare the performance of each alternative; cost was calculated separately, and later compared to the overall performance of each alternative. The body of the table contains the definition of each evaluation measure, which describes how the EM was calculated. The range and format of expected values of the EM are defined, and the rationale and relevance describes what the EM measured, and why the EM was used to compare alternatives.

	Percentage of Traceable Measures	**Days to Plan Evaluation**	**Quality of Planning Products**	**Elasticity of Labor**	**Elasticity of Duration**
JC3M Function	Define Measures 1.3.2	Planning Results 1.4.3	Planning Results 1.4.3	Input System Flexibility 4.1	Input System Flexibility 4.1
Definition	Alternative generated measures, traceable to stakeholder requirements, divided by the number of measures generated by the alternative. Ratio level data, from 0 – 100%	Elapsed time (in days) of planning for C4I SoS evaluation Ratio level data $\geq$ 0 days	Assign an overall quality level to the planning documents produced. Ratio level data from 1 - 4	Divide percent change in labor hours to conduct planning phase of JC3M by the percent change in systems under test. Ratio level data from 0 – ∞	Divide percent change in duration to conduct planning phase of JC3M by the percent change in systems under test. Ratio level data from 0 – ∞
Rationale and Relevance	Identifies objectivity of performance measures. Performance measures traceable to doctrine will be perceived as objective, increasing the value of the evaluation.	Predicts SoS evaluations that can be conducted in a year. Alternatives that permit multiple SoS evaluations generate data to support fielding decisions sooner.	Identifies predicted utility of alternative. Quality of the planning products drives the overall value of the alternative.	Predicts changes in cost of SoS evaluation based on size. Can be used to determine most effective alternative based on SoS size.	Predicts changes in duration of SoS evaluation based on size. Can be used to determine most effective alternative based on SoS size.

Table 1. JC3M Critical Evaluation Measures.

This table illustrates Critical EM used to compare the performance of alternative solutions. Dimension of the measure (Nominal, Ordinal, Interval, or Ratio-level data) is provided. Rationale for, and relevance of, the EM is also provided. Note “Quality of Planning Products” is expressed on a Likert Scale as described in Appendix C.

III. DESIGN ALTERNATIVES

The goal of the Design Alternatives phase was to provide possible JC3M solutions that were broad enough in approach to present stakeholders with a viable range of approaches to the problem, yet few enough in number so as to be capable of analysis within project constraints. The Design Alternatives phase consisted of three tasks: Alternative Generation, Feasibility Screening, and establishing Criteria for Scoring.

Alternative Generation took the outputs from the Problem Refinement phase, including the problem refinement report and JC3M value hierarchy with evaluation measures, and created a range of alternative solutions to focus on solving the JC3M problem statement – identifying objective threshold values for measuring SoS performance. Alternative Generation also included the consideration of known alternatives: the status quo, a near-term future solution, and a long-term future solution. With three known alternatives, the team generated two new alternatives to present a sufficiently broad range, yet still maintain the ability to conduct a thorough analysis.

Feasibility Screening was used to evaluate the variety of alternatives, and identify those which appeared to be feasible, different from the baseline and other alternatives, and few enough in number to be effectively analyzed within the scope of the project. The output of this process was a smaller set of feasible alternatives.

Criteria for Scoring were established based on EM, problem refinement report, and the JC3M value hierarchy tree in order to identify those criteria which would be later used for comparing the alternatives. This process also identified those EM which would be drawn from the simulations of the alternatives. Outputs of this process included the scoring criteria identified, as well as a blank quantitative modeling decision matrix.

A. ALTERNATIVE GENERATION

The team identified known alternatives for inclusion in the set of possible JC3M solutions by reviewing historical processes, interviewing current stakeholders, and participating in new system development.

1. Known Alternatives

a. Federation of Systems

The first known alternative was the FEDeration Of Systems (FEDOS) process used at MCTSSA. FEDOS was a user-driven process, with C4I program managers collectively defining the configuration of the C4I SoS [Manning (c), 2007].

FEDOS was designed to assess the performance of C4I systems when assembled into the Marine Air Ground Task Force (MAGTF) C4I SoS. FEDOS began at the order of the Deputy Commander for C4I Integration and Interoperability (C4II) at MARCORSYSCOM, who tasked MCTSSA to assess MAGTF C4I SoS and systems interoperability. FEDOS was created because there were processes to assess the interoperability and performance of a C4I system, but none to assess the performance or interoperability of the C4I SoS. The Deputy Commander for C4II assembled a working group of stakeholders from the C4I system community at MARCORSYSCOM, and tasked MCTSSA to assign a test director. The working group decided what systems would participate, what requirements were to be tested, and the schedule of events to include test planning, test conduct, and results reporting.

Because FEDOS provided an opportunity to evaluate the performance of C4I systems in the SoS, it was also used to evaluate performance of developmental systems. CONDOR, as an example, was developed to provide communications connectivity to units physically distant from stationary long haul communications paths. CONDOR was included in a June 2005 FEDOS event, prior to deployment to Iraq in September 2005.

The MARCORSYSCOM Product Groups, responsible for developing, fielding, and supporting C4I systems, were not required by order or doctrine to participate in FEDOS, and a passing grade from FEDOS was not a requirement for a milestone decision. This led to the perception of FEDOS as a cost, schedule, and performance risk, which in turn led to ineffective participation from acquisition community representatives.

Because the MAGTF C4I SoS was not designed in compliance with architecture, there are no overarching C4I SoS performance measures or threshold criteria. This lack of doctrinal C4I SoS performance criteria meant that MCTSSA test personnel had to engage in long and at times inconclusive negotiations with stakeholders in order to define the threshold values that were used to measure SoS performance, and determine if components passed or failed the test. The Product Groups viewed the results of FEDOS askance, as the event results were not tied to objective SoS-level performance requirements.

Further, FEDOS was perceived as a no-win situation for Product Groups. After a system had successfully passed Development and Operational Tests, and demonstrated compliance with system-level performance requirements as described in the Capability Development Document (CDD), Operational Requirements Document (ORD), or equivalent, FEDOS tested component systems in ways they had not been designed to be used.

The conduct of FEDOS, outlined in Figure 12, was organized in a series of events, each of which culminated in a decision point known as a "Control Gate." Each gate represented a milestone that had to be reached before the planning effort could continue. The gates included agreements on what was under test, how the network would be configured, how the systems would be evaluated, what specific test procedures would be used, interpretation of results, and the contents of the test plan.

Both execution and reporting of SoS evaluation results have effective processes in place; JC3M focuses on the planning of SoS evaluations. For the purposes of this project, only the initial, Planning phase of FEDOS was considered as a candidate alternative JC3M solution. This phase consisted of three tasks as discussed below.

In Task 1, the team elicited test requirements. This was done by analysis of stakeholder inputs and identified hardware and software versions, test schedule requirements, and functional test requirements. The functional requirements were determined based on the SoS capabilities that were to be exercised in order to evaluate the SoS as requested. Additionally, documentation and data collection requirements were identified, as well as customer communications requirements. After stakeholder review, changes were incorporated into a final list of test requirements to be presented at the control gate exit from Task 1. This requirements list included a draft SoS components list, draft project schedule, draft functional requirements and architecture, draft documentation and data collection plan, and draft customer communications plan. Figure 12 provides an illustration of the serial processes in FEDOS. Figure 13 provides a detailed view of FEDOS Task 1.

Task 2 generated an evaluation plan. The FEDOS team reviewed Task 1 outputs and generated draft Test Thread Architecture diagrams, and reviewed with stakeholders. As stakeholder approval was received for the test thread architecture, draft test thread descriptions were generated. Draft metrics and a grading process were generated and reviewed with stakeholders. Finally, a draft Evaluation Plan, containing the draft architecture diagrams, test thread descriptions, and grading process was assembled and reviewed with stakeholders. After review, incorporation of requested changes, and assembly of the final evaluation plan, the stakeholders had to agree to the evaluation plan as another control gate.

Task 3 generated a test plan and test procedures. The team created a draft test plan, incorporating outputs from Task 1 (requirements list) and Task 2 (evaluation plan). A test procedure format was chosen, reviewed with stakeholders, and used to document the test procedures proposed for the event. Both the test plan and procedures were reviewed in detail and presented to stakeholders for approval. Once the test plan and the test procedures were approved, the planning phase of FEDOS was concluded.

Because FEDOS was the only alternative solution that had been used by a C4I test organization, it was considered the “status quo” or baseline JC3M alternative solution.

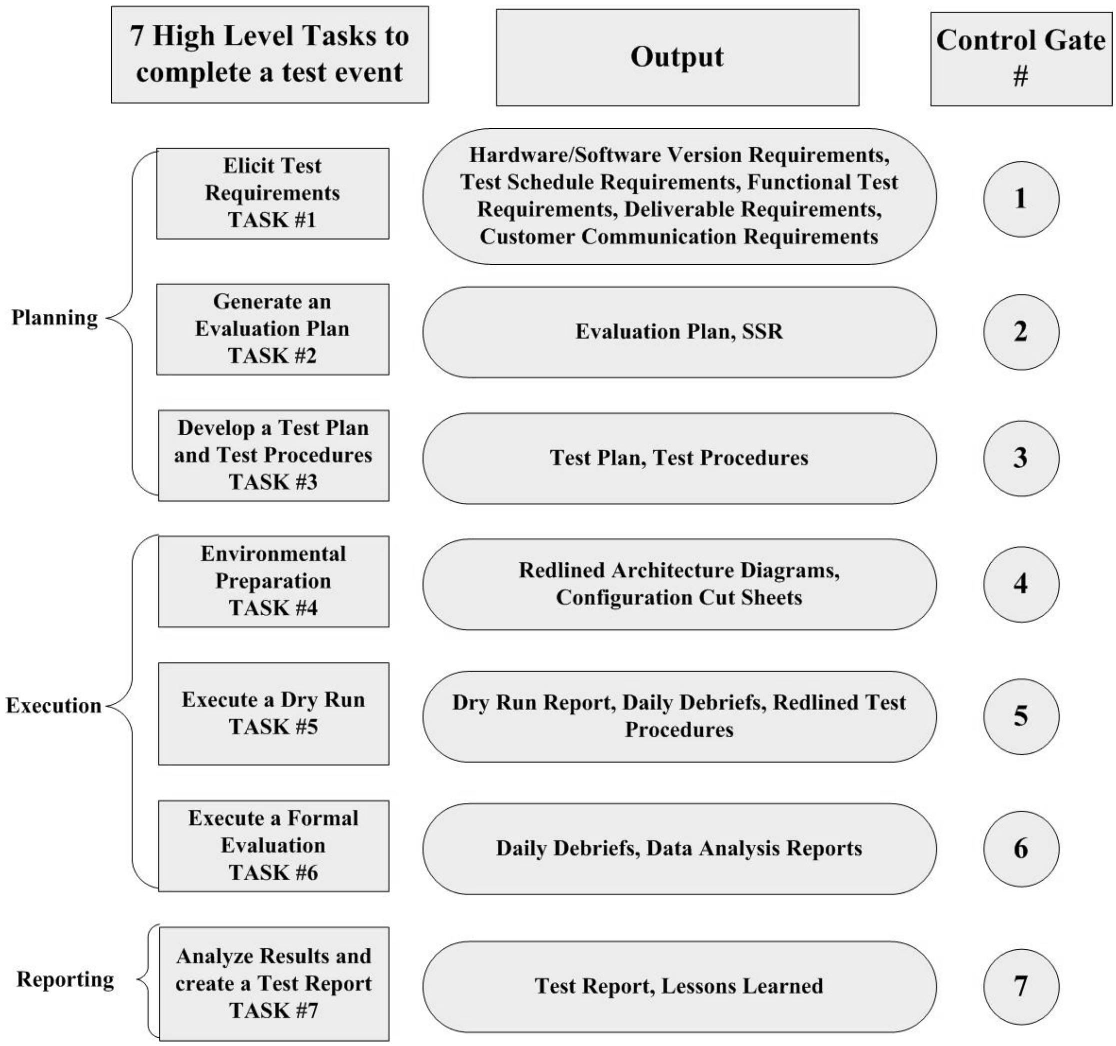

Figure 12. FEDOS Process.

FEDOS has 7 tasks to complete a test event; JC3M will consider the Planning Phase (Tasks 1 through 3) of FEDOS as an alternative JC3M solution. Each task (identified in a block) has outputs (listed in an oval). Each task proceeds when a control gate (identified by a numbered circle) is completed. (See Figure 13 for a detailed example of FEDOS Task 1.)

FEDOS phases were executed in a serial manner, requiring explicit approval from all stakeholders before commencement of subsequent tasks. The serial nature of FEDOS can be seen in Figure 13, which illustrates only Task 1 of the FEDOS process.

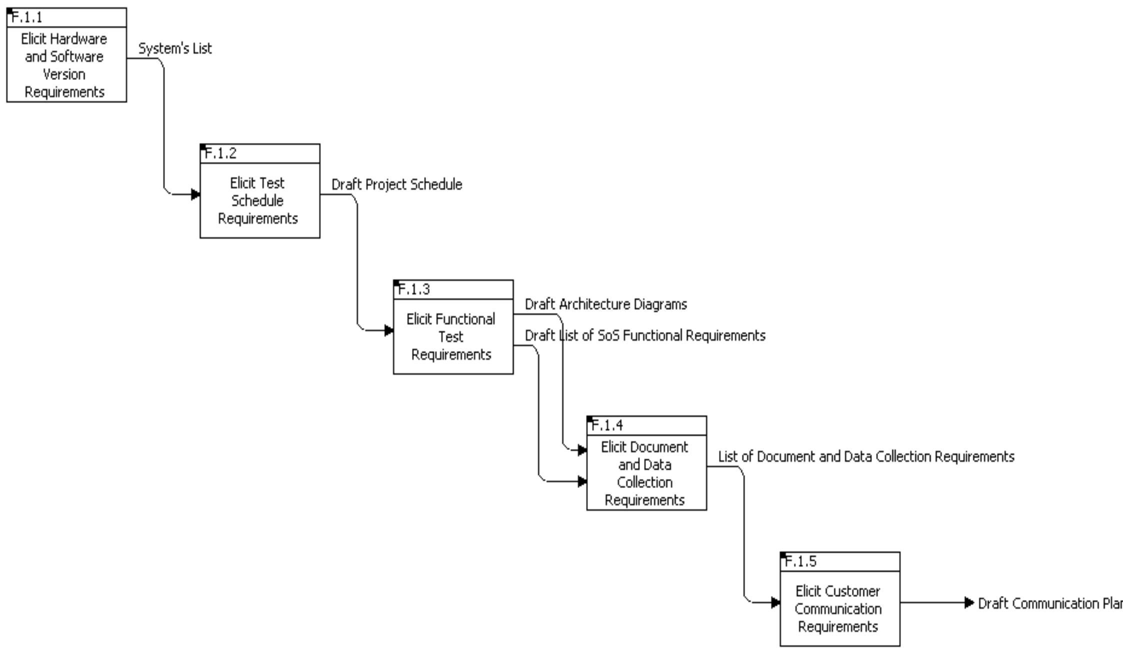

Figure 13. FEDOS Task 1 Elicit Test Requirements.

This IDEF0 illustration of the FEDOS "Elicit Test Requirements" task portrays the subtasks ("Elicit Hardware and Software Version Requirements") used to generate the outputs identified in Figure 12. Each process contained exit criteria used as a control gate; all stakeholders had to agree on the outputs of a process before the next process started. IDEF0 illustrations of each alternative are provided at Appendix F.

b. Marine Air Ground Task Force Command, Control, Communications, Computers, and Intelligence Capability Certification Test

MC3T, a system for defining, documenting, and evaluating the performance of a MAGTF C4I SoS [Finn, 2007], was identified as the second known alternative. MC3T was implemented as a replacement for FEDOS at MCTSSA.

MCTSSA was charged by MARCORSYSCOM with developing, planning, executing, and reporting on a proof of concept event to be conducted in October 2007. Three members of this Capstone project team have been actively engaged in the development and implementation of MC3T, and will continue to support MC3T as planning, execution, and reporting are conducted. Other MC3T participants include U.S. Navy Space and Naval Warfare Center (SPAWAR) Systems Center, Charleston, S.C. and U.S. Marine Corps Combat Development Command (MCCDC).

The first MC3T event will not develop C4I SoS measures of performance for consideration, due to time constraints, and will instead be used to prove the validity of MC3T processes. During and after the first iteration of MC3T, stakeholders will review results to determine if this system will be continued, modified, or replaced. Because this review period will occur shortly after the delivery of this JC3M final report, MC3T stakeholders are interested in reviewing JC3M results for possible inclusion in future MC3T events.

MC3T has been developed by an Integrated Product Team (IPT) made up of stakeholders from MCTSSA as well as representatives of the MARCORSYSCOM Product Groups. Product Group representatives defined a "Capabilities Package" complete with System requirements, and DoD Architecture Framework Operational views and System views that depicted the systems under their cognizance. MCTSSA analyzed the Capabilities Package and produced a Consolidated Requirements Assessment (CRA). The CRA was an agreement between the stakeholders on what needed to be tested, what the required resources were, what the Information Assurance compliance requirements were, and what the draft test dates were. Once the CRA was approved, MCTSSA produced a Technical Proposal.

The Technical Proposal defined the technical solution the IPT proposed to meet the requirements in the CRA in: staffing, C4I systems architecture design, monitoring network architecture design, test cases, data capture and analysis plan, information assurance plan, and risk assessment.

Once the Technical Proposal was confirmed, it became the Technical Solution. The Technical Solution made up approximately 90% of the Test Plan and included detailed test procedures and additional reference documentation.

c. *Joint Test and Evaluation Methodology Capability Test Methodology*

The JTEM CTM was chosen as the third alternative. The purpose of JTEM is to

> …develop, test, and evaluate M&P [Methods and Processes] for defining and using a distributed LVC [Live, Virtual, and Constructive] joint test environment to evaluate system performance and joint mission effectiveness. JTEM will focus on developing and enhancing M&P for designing and executing tests of SoS… [JTEM Rock Drill Event Final Report, 2007: i].

The five phases of the JTEM CTM are Characterize Test; Plan Test; Implement Live, Virtual, Constructive Distributed Environment; and Execute Test [JTEM CTM M&P Model Description, 2007: 4-5]. Phases 1 and 2 (Characterize Test and Plan Test) are considered as a combined alternative JC3M solution and are described below.

CTM.1 Characterize Test

"Initial planning negotiations concerning test program concepts and test capabilities are conducted during the Characterize Test phase. Program characterization processes include developing the joint operational context for testing, developing the test concept, and developing the test's evaluation strategy. Test capability characterization processes include technical assessment producing an initial LVC distributed environment test design and programmatic assessment involving high-level test scheduling and test resource estimates. Information product inputs to Characterize Test relevant to developing joint operational context for testing include the critical CDD, as well as the Initial Capabilities Document (ICD), JOpsC Family products, the Universal Joint Task List (UJTL), Defense Planning Scenarios (DPS), Combatant Command (COCOM) operation plans/orders (OPLAN/OPORD), and the Test and Evaluation Master Plan (TEMP). Characterize Test product inputs relevant to test concept and evaluation development include an approved AoA plan, test and evaluation strategy, TEMP, and operational test plan. The Characterize Test phase produces a test program introduction document (PID) and statement of capabilities (SOC)" [JTEM CTM M&P Model Description, 2007: 4].

CTM.2 Plan Test

"During the Plan Test phase, test concepts … are further developed into a test plan. Test Planning processes include developing the test design, performing … environment analysis, and coordinating test support, and the synthesis of these processes by developing the overall test plan. Developing the test design involves producing test vignettes and a data management and analysis plan (DMAP). Performing … environment analysis produces a … Functional Description. Also, test support coordination produces test support plan products. The Plan Test process then produces an overall Test Plan, incorporating all identified products from this phase.

"This Level I division into separate process phases is somewhat of an abstraction and a simplification of what occurs in a real test cycle. Many of the Level I phases and lower level processes are iterative in nature. Many processes are performed in parallel, and the results of these processes are fed back into the iterative work of other processes" [JTEM CTM M&P Model Description, 2007: 4].

The JTEM CTM was tested in a limited scope during 2007, but the development of the CTM will not be complete until 2009. The CTM will not be executed during the conduct of the JC3M project. The team considered phases 1 and 2 as an alternative JC3M solution. All five phases of the JTEM CTM are illustrated in Figure 14.

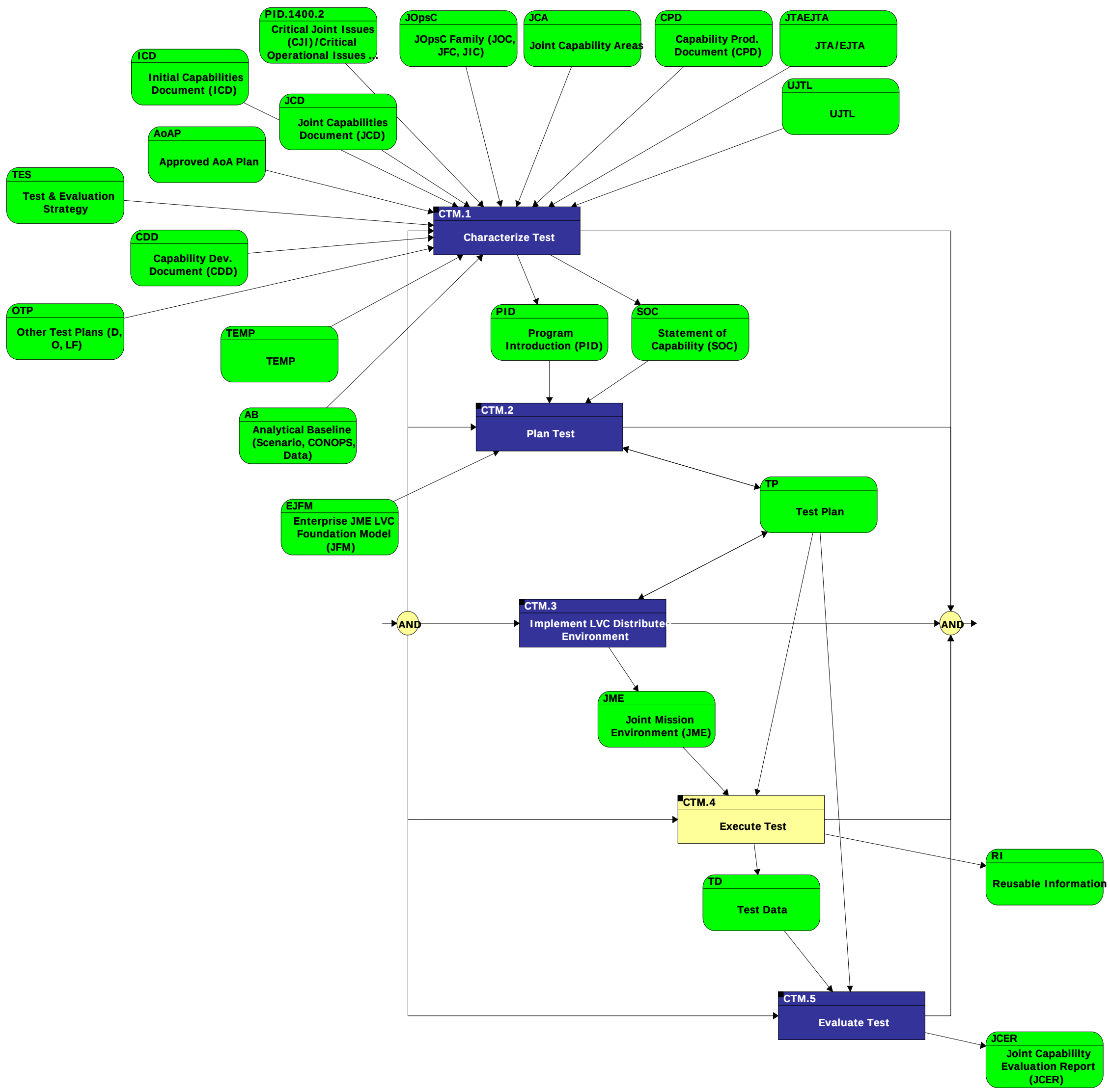

Figure 14. JTEM CTM Phases

JTEM CTM processes are pictured; JC3M will consider the first two phases (Characterize and Plan) as an alternative solution. Dark Blue boxes are CTM phases; Green, round edge boxes are inputs and outputs; Execute Test is identified in yellow as a simulated event performed in JTEM CTM development. CTM 1 and CTM 2 are considered as a JC3M alternative solution [From JTEM CTM M&P Model Description, 2007: 4].

2. Generating New Alternatives

Systems Engineering practice and critical thinking [Paul et al., 2006: 23] call for exploration of a full range of options in order to provide good solutions. Alternative solutions must be evaluated through a fair minded [Paul et al., 2006: 6] and logical process, using quantitative and qualitative methods to determine the optimum solution for the JC3M system.

The known alternatives discussed above represent the current state of C4I SoS evaluation systems, and reflect the resource, risk, and organizational constraints in effect at the creation of these systems. The JC3M team generated new alternatives to provide a fresh perspective on the problem, in an attempt to generate a better range of solutions. The team determined that two new alternatives, in addition to the three known alternatives, would provide stakeholders a meaningful range of potential solutions to consider. Limiting the alternatives to five would also limit the modeling, simulation, cost estimation, and analysis tasks to a scope that could be managed over the duration of the project.

To produce the new alternatives the team utilized a morphological box [Zwicky and Wilson, 1967: 9] as a tool to both guide the process and record the results.

3. Morphological Box Process

The morphological box ("Zwicky Box") process began by defining the parameters of importance to the problem. For the problem under consideration, the JC3M functional hierarchy was used to define the critical parameters to be investigated. These top level functions were Define the Problem, ID Systems Under Test (Components of the SoS), Define Criteria, and Ensure Readiness.

A matrix, containing all the potential solutions of the problem, was created. The team used brainstorming to generate potential solutions for each separate JC3M system function. The brainstorming process consisted of proposing potential solutions for each separate JC3M function without consideration of cost, for feasibility, accuracy, speed, or any other factor. Ideas were not evaluated, but recorded in a non-graded manner under the respective functional column of the alternative matrix. This process was repeated for each JC3M system function until the team could not identify or generate any additional concepts.

All of the generated potential functional solutions were evaluated, and after clearly redundant entries were eliminated, the remaining potential function solutions were as depicted in Table 2.

Define the Problem	**ID Systems Under Test**	**Define Criteria**	**Ensure Evaluation Readiness**
Have Subject Matter Experts do it	Engineering Document review	Experience from earlier test	Test Manager Review
Get from CDD	Depart of Defence Architecture Framework (DoDAF) Document Review	Ask JITC	Program Manager (PM) Review
Conduct survey	Previous Systems Under Test	Ask users	Cost Driven
Test agency defines	Ask JITC	"Trouble Calls" recorded on issues	All Stakeholders Review
JITC defines	ORD/CDD review	Build from SoS Capabilities	Planning is finished
Stakeholders define	Field Concept of Operations	Look at Peers (Joint, Service)	Schedule Driven
Acquisition manager defines	What PM requested	What PM asked for	Subject Matter Expert Review
JTEM defines	Changes to SoS from last test	Changed capability or function in SoS	Dry Run Test (and see if it works)
Ad hoc definition	Functional Breakdown	Work Breakdown Structure	Modeling of test plan
Last definition used in previous test	Bottom up review	Hardware or Software Upgrade	Run-Test-Run
Users define	Test everything	Ask SPAWAR	JITC Definition
User requirements	Whatever changed	Test everything	SAR Review
What is changed in SoS	Test agency determines	"Just Do It" (no specific guidance)	ORD/CDD Crosswalk
Current issues seen by SoS users	System Anomaly Report review (SAR)	ORD/CDD Review	Change in Test Plan from previous event
(SAR) Generation	SAR System ID	Trouble calls from the field	
Don't Define It		Stakeholder Review	

Table 2. JC3M Morphological Box.

Potential solutions identified for each JC3M sub-function, as generated by Zwicky Box process. Top Row is the list of functions, and each cell below it represents a proposed solution to that issue, in isolation.

Once the team had identified a number of potential solutions for each function, the separate potential solutions had to be assembled into a cohesive package for consideration as an alternative. One goal of this stage was to identify alternatives that are distinctly different. Another goal of this stage was to identify those approaches which are attractive, viable, or possible, and to eliminate the approaches which are not attractive, viable, or possible.

The team considered each potential solution to a function separately, and then compared the list of potential solutions for the next function in series, looking for similarities in theme. As an example, for the "Define Problem" function, one proposed approach was to consider "What is changed in SoS." In order to perform the "ID Systems under test" function, one proposed approach was to consider "Whatever changed." For the "Define Criteria" function, one proposed approach was to consider "Changed capability or function in the SoS." For the "Ensure Evaluation Readiness" function, one approach was to consider "Change in Test Plan from previous event." All these approaches had the common theme of reviewing only what had changed from a previous evaluation, so these were assembled into an alternative. The name for this alternative was assigned after members of the team proposed that the underlying theory was to consider "what has changed."

After review of all potential solutions, nine different alternatives were created by linking themes. Table 3 below shows the nine alternatives, named for the theme underlying the individual approaches. A detailed description of the proposed alternatives is included in Appendix D.

Alternative Name	Define Problem	ID Systems Under Test	Define Criteria	Ensure Evaluation Readiness
Exhaustive	Don't Define It	Test everything	"Just Do It" (no specific guidance)	Run-Test-Run
User Defines	Stakeholders-define	What PM requested	Ask users	All Stakeholders Review
Do No Harm	JITC defines	Ask JITC	Ask JITC	JITC Definition
System Anomaly Report	SAR Generation	SAR System ID	Trouble calls from the field	SAR Review
Deliberate Method	Stakeholders define	Functional Breakdown	Stakeholder Review	Modeling of test plan
Capabilities Documentation	Get from CDD	ORD/CDD review	ORD/CDD Review	ORD/CDD Crosswalk
Program Manager Direction	Acquisition manager defines	What PM requested	What PM asked for	PM Review
Test Agency Direction	Test agency defines	Test agency determines	Experience from earlier test	Test Manager Review
Change Driven	What is changed in SoS	Whatever changed	Changed capability or function in SoS	Change in Test Plan from previous event

Table 3. JC3M Alternatives.

Initial JC3M potential solutions, based on JC3M sub-functions, and generated by Zwicky box process. Proposed alternatives are composed of like approaches to sub-function challenges.

B. FEASIBILITY SCREENING

After alternative generation, the JC3M project team reviewed the group of potential alternatives to eliminate those which were clearly infeasible, in order to reduce wasted effort. The team also reviewed the group of potential alternatives to eliminate those which were very similar, in order to present stakeholders with feasible alternatives that were sufficiently different so as to provide a variety of approaches.

After reviewing the nine alternatives from the standpoint of feasibility and similarity, the User Defines alternative was eliminated from further consideration because it was very similar to the Program Manager Defines alternative.

The Do No Harm alternative was eliminated because the team planned to consider the performance of baseline processes from other organizations (JTEM, MC3T, MCTSSA) from the start, and a primary goal of this alternative generation process is to consider two entirely new alternatives, rather than exclusively baseline processes.

The Capabilities Documentation alternative was eliminated because it is similar to the SAR alternative in that both alternatives rely on outside documentation for identification of threshold values.

The revised list of alternatives was left as Ad-Hoc, SAR, Deliberate Method, Program Manager Direction, and Change Driven. The team completed this process with a smaller set of feasible and sufficiently varied alternatives which could be analyzed over the course of the project. In this manner, feasibility screening reduced the nine alternatives seen in Table 3 to five, as seen in Table 4. A detailed description of the feasibility screening process is included at Appendix D

Because the FEDOS alternative represented the baseline for C4I SoS evaluation performance, each alternative was compared to the baseline for each EM. The team reviewed the known performance of the baseline against the projected performance of the alternative processes. The scoring criteria were as follows: (+) the alternative was expected to perform better than the baseline, (-) the alternative was expected to perform worse than the baseline, and (=) the alternative was expected to perform the same as the baseline. After evaluating each alternative, the (+) values were summed and the (-) values were subtracted, to calculate a final score. Deliberate Method and Change Driven alternatives were ranked highest, as displayed in Table 4.

Evaluation Measures	Ad-Hoc	SAR	Deliberate Method	PM Direction	Change Driven
Percentage of traceable thresholds	=	+	+	+	+
Percentage of Capabilities Identified	=	+	+	+	=
Time to Plan Evaluation	+	=	=	=	+
Number of Traceable Thresholds Identified	=	+	+	+	+
Percentage of Shortfalls Identified	=	=	+	=	=
Quality of Planning Outputs	=	=	+	=	=
Number of C4I Systems Under Test	=	=	=	=	=
Percentage of Interfaces Identified	=	=	+	=	+
Total +	1	3	6	3	4
Total -	0	0	0	0	0
Overall Total	1	3	6	3	4

Table 4. Reevaluated JC3M System Alternatives Datum Design Comparison Matrix.

This table illustrates the results of the screening of alternatives. The expected performance, by function, of each of the potential alternatives solutions was compared to the performance of the FEDOS process. Where the potential solution was projected to be superior, a "+" is recorded; where inferior, a "-" is recorded. Comparable performance is recorded with "=", and the overall comparisons are summed. "Deliberate Methods" and "Change Driven" had the highest scores of the potential alternatives.

1. Alternative Refinement

After identifying the most promising new alternatives for consideration as JC3M solutions, the team began detailed design of these alternatives, prior to developing simulations to evaluate the performance of each alternative.

In referring back to the original problem statement, the team determined that threshold performance criteria must be traceable back to doctrinally correct sources, or else they would be perceived as based on personal opinion, rather than Service or DoD requirements. In order to provide the most accurate, doctrinally sound, and traceable performance measures, the team searched for doctrine guidance, and found it in the form of the UJTL. The UJTL is a "…comprehensive integrated menu of functional tasks, conditions, measures, and criteria supporting all levels of the Department of Defense…" [CJCSM 3500.04D, 2005: A-1].

The UJTL provides a description of what combatants, combat support agencies, and DoD activities must perform. More importantly to JC3M, the UJTL provides a list of performance measures and criteria for use in an evaluation. There are also Service-specific subsets: the Army Universal Task List and the Universal Naval Task List (used by the U.S. Navy, U.S. Coast Guard, and U.S. Marine Corps).

After some investigation, the team found that doctrinal references provide measures (speed, accuracy, duration, % of enemy forces destroyed, etc.) but not the threshold values. As an example, OP 3.2.6, "Provide Firepower in Support of Operational Maneuver" is a task in the UJTL, and measures include both time to engage and accuracy of engagement [CJCSM 3500.04D, 2005: B-B-2].

In the accuracy measure, percent of enemy forces destroyed, delayed, disrupted, or degraded is evaluated [CJCSM 3500.04D, 2005; B-B-2]. The UJTL does not state what "percent of enemy forces destroyed" is sufficient to constitute success. The threshold value is left out by design, in order to allow the commander the flexibility to set a threshold in accordance with the mission, the conditions, and the situation.

Service-level guidance was reviewed as well. Marine Corps Training and Readiness Manuals list measures and criteria, but they focus on functions and not capabilities. As an example, the [Artillery T&R Manual, 2000: 3-IF-45] describes the task of controlling a battery of towed artillery pieces moving in a convoy, and responding to an emergency request for artillery support by halting and placing the guns to fire on a target. "Lay the Battery for an Emergency Fire Mission (Hip Shoot) while in a Convoy" is stipulated as a performance task, but the criteria are not provided.

The team determined that an attempt to define threshold performance values would violate the spirit, if not the letter, of DoD and Service level guidance. Further, if the JC3M system were to define threshold performance values, in spite of DoD guidance to the contrary, the recommended thresholds would be subjective, and subject to immediate challenge by operators, subject matter experts, acquisition managers, and other testers. If the results of a test are perceived to be subjective, they are worth very little.

The team also investigated process or system based solutions which could generate threshold values, but could not find any such solution. There are tools in development [Lockheed, 2007] that will assess conformance to standards and interoperability based only on technical exchange of information. Tools will not compare performance for end-to-end operational effectiveness for mission accomplishment, only compliance to a technical standard. Interoperability must include ". . . both the technical exchange of information and the end-to-end operational effectiveness of that exchanged information as required for mission accomplishment" [CJCSI 3170.01F, 2007; GL-9].

Based on the number of possible conditions, missions, unit types, and components of the SoS, the team determined it would be futile to try to create a tool that could account for all the combinations

2. JC3M Changes

Without doctrinal sources for, or processes to generate, threshold criteria, the team determined that there were several potential changes to JC3M. One recommendation to stakeholders could be to assemble the SoS as described by stakeholders, test against performance measures, then record the performance. This would establish a baseline of performance values, so that when SoS components were changed in the future, testers could ascribe the changed results to changed components. ("With Box X, missile speed was 620 mph; with Box Y installed in place of Box X, and everything else held constant, missile speed was 670 mph.") The before and after comparison would be very objective, and would allow stakeholders, not testers, to determine if the performance was acceptable. This is the methodology used at Naval Surface Warfare Center (NSWC) Corona Division, and will be used by MC3T at MCTSSA for the proof of concept event in October 2007.

Another methodology would be to recommend that testers use doctrinal references to objectively define only measures, test the SoS to evaluate its performance on those measures, and report the results to the stakeholders ("87% of enemy forces were destroyed"). This approach depends on the ability to assess combat-focused performance on measures that are not typically available in a test organization for space, time, and safety constraints. While simulations can be used to accomplish this approach, this adds another layer of complexity to the conduct of a C4I SoS evaluation, as well as the potential for challenges to the evaluation methodology, based on the implementation of the combat simulations. This approach was considered, but because JC3M is focused on objective measures, it was not considered.

Another methodology would be to recommend further emphasis on the JCIDS, with all future acquisitions made on a SoS level, with objective performance criteria at an operational level identified in JCIDS documents before acquisition. This is, in the long run, the best answer for DoD, but does not address the many legacy C4I systems that are assembled, after the fact, into a SoS. This is also in line with the concept of capability portfolio management ordered by Deputy Secretary of Defense Gordon England in 2006. In a memo defining capability portfolio management roles and responsibilities, Secretary England stated the intent is to "… manage groups of like capabilities across the enterprise to improve interoperability, minimize capability redundancies and gaps, and maximize capability effectiveness" [England, 2006: 3]. The memorandum also charged the Joint C2 Capability Portfolio manager to create a test case that "…delivers integrated joint capabilities, which improve interoperability, minimize capability redundancies and gaps, and maximize joint operational effectiveness" [England, 2006: B-1]. The Joint C2 Capability Portfolio manager, with three other portfolio managers, worked on the 2008 DoD Budget request, which started the process of adjusting Service C2 programs [Federal Computer Week, 2007]. While an excellent long-term solution, this does not address the immediate need for performance measures to use in evaluating legacy C4I SoS.

The team chose to use JC3M to define performance measures only, and use those measures to test the C4I SoS. This represents a change to the JC3M effective need, i.e. instead of pursuing threshold performance values ("60 mph is the passing criteria"), JC3M will define the performance measures to be used in the evaluation of a C4I SoS ("measure the speed of the vehicle").

The team reviewed the generated alternatives and determined they would have been effective when the original goal of JC3M was to provide a method for organizations to define threshold performance criteria for use in C4I SoS evaluations.

When documenting the processes that comprise each of the alternatives, prior to creating models, the modeling and simulation team determined that in defining C4I SoS performance measures, both Deliberate and Change-Driven alternatives performed the same functions, in the same manner. As originally defined, each model took the same external data sources (the UJTL, Systems Engineering Artifacts, and system-level documentation) into consideration when defining performance measures. The alternatives differed in how they performed the next step, i.e. identifying the threshold values which were the goal of the original JC3M solution. Because those threshold values were no longer pursued, the final and discriminating phase of each alternative was eliminated. With that elimination, the modeling and simulation team determined that PM Direction and SAR would perform exactly alike, thus eliminating their value in presenting different approaches to the JC3M solution.

The team generated two new alternatives to meet the revised JC3M requirements, utilizing the same functions that drove the first round of alternative generation, again using the "Morphological Box Process" described in Chapter III section A.3.

a. Systems Capabilities Review Alternative

The Systems Capabilities Review (SCR) alternative is a combination of the "Capabilities Documentation" alternative and the "Test Agency Direction" alternative outlined in Table 3. SCR is composed of a group of stakeholders: C4I system and SoS user representatives, test agency representatives, system developers, system designers, and program managers. The test agency representative chairs the group, which meets as required to support a C4I SoS evaluation, at the Systems Command level.

Inputs to SCR include source documents such as the Capabilities Development Document (CDD), Operational Requirements Document, Test Plans, TEMPs, Concept of Operations documents, Joint Integrating Concepts, Joint Operating Concepts, and system level metrics.

The SCR first reviews SoS capabilities specifications, and will examine the systems engineering artifacts already created, such as supporting DoD Architecture Framework documents and technical performance measures, and creates a list of implied and stated SoS capabilities. Next, the SCR reviews system-level documents and creates a system-level capabilities list. Third, the SCR maps system-level capabilities to SoS EM. The SCR identifies gaps in the EM list, and creates the balance of the EM necessary to evaluate the performance of the C4I SoS. Figure 15 illustrates how SCR performs the JC3M subfunction 1.3.2 "Define Measures."

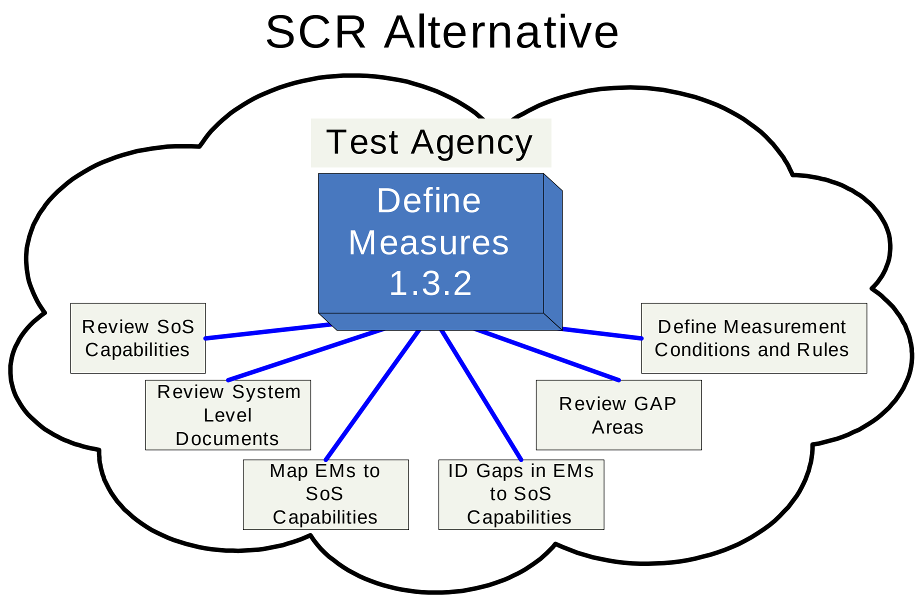

Figure 15. List of Sub Tasks Performed by SCR to Define Measures.

The JC3M Functional Hierarchy calls for function 1.3 "Define Evaluation Criteria." This function is supported by JC3M subfunction 1.3.2 "Define Measures." The SCR alternative, in order to support 1.3.2, performs sub processes. Each of the subprocesses may have multiple submissions from C4I SoS evaluation stakeholders.

The subtasks performed by SCR as part of Task 1.3.2 “Define Measures” are illustrated in more detail in Figure 16.

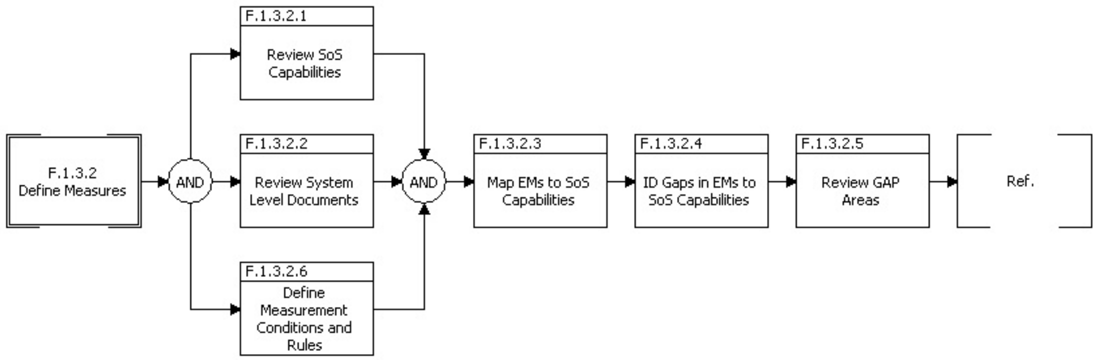

Figure 16. SCR Define Measures Subtask Ordering.

This figure illustrates the subtasks broken down in the order in which they are performed in the SCR alternative. Review SoS Capabilities, Review System Level Documents, and Define Measurement Conditions and Rules can be worked in parallel. Once these tasks are complete the team maps EM SoS capabilities and reviews gap areas. These functions are consistent with the more detailed functional analysis performed on the new alternatives. “REF” is a CORE artifact, and indicates no additional function is enabled when this flow completes.

b. Functional Capabilities Board Alternative

The Functional Capabilities Board (FCB) alternative is based on an existing group, the JCIDS C2 Functional Capabilities Board, to define the performance measures of the C4I SoS. Figure 17 illustrates the tasks of an FCB, which is to perform “. . . organization, analysis, and prioritization of joint warfighting capabilities within an assigned functional area” [CJCSI 3170.01F, 2007; GL-7]. Inputs to the FCB include the UJTL and subsets, Concept of Operations (CONOPS) documentation, Program Change Request documentation, and system trouble reports.

Standing FCBs evaluate shortfalls and gaps in current and future capabilities as they are identified by studies or assessments, or arise from processes or meetings [CJCSI 3137.01C, 2004: E-1]. The FCB reports are provided to the Joint Capabilities Board (JCB) or Joint Requirements Oversight Council (JROC). The additional effort proposed in this alternative represents an increase in the work performed by the C2 FCB, but is in the same functional area, and engages in many of the same tasks. Unlike the SCR, the FCB meets on an ongoing basis, rather than as required to support C4I SoS evaluations.

The FCB will first identify the configuration of the SoS by determining the component systems. Next, the FCB will identify the SoS capabilities. SoS CONOPS are reviewed to determine EM, and finally the FCB will generate the SoS EM list for use in C4I SoS evaluations. The FCB, under JCIDS, has a long-term perspective and charter. The FCB represents a near-term resource that can provide ongoing analysis, and so reduce the lack of C4I SoS performance measures. The FCB appears to explicitly support the concept of capability portfolio management, but the JC3M team could not find any information to confirm that relationship.

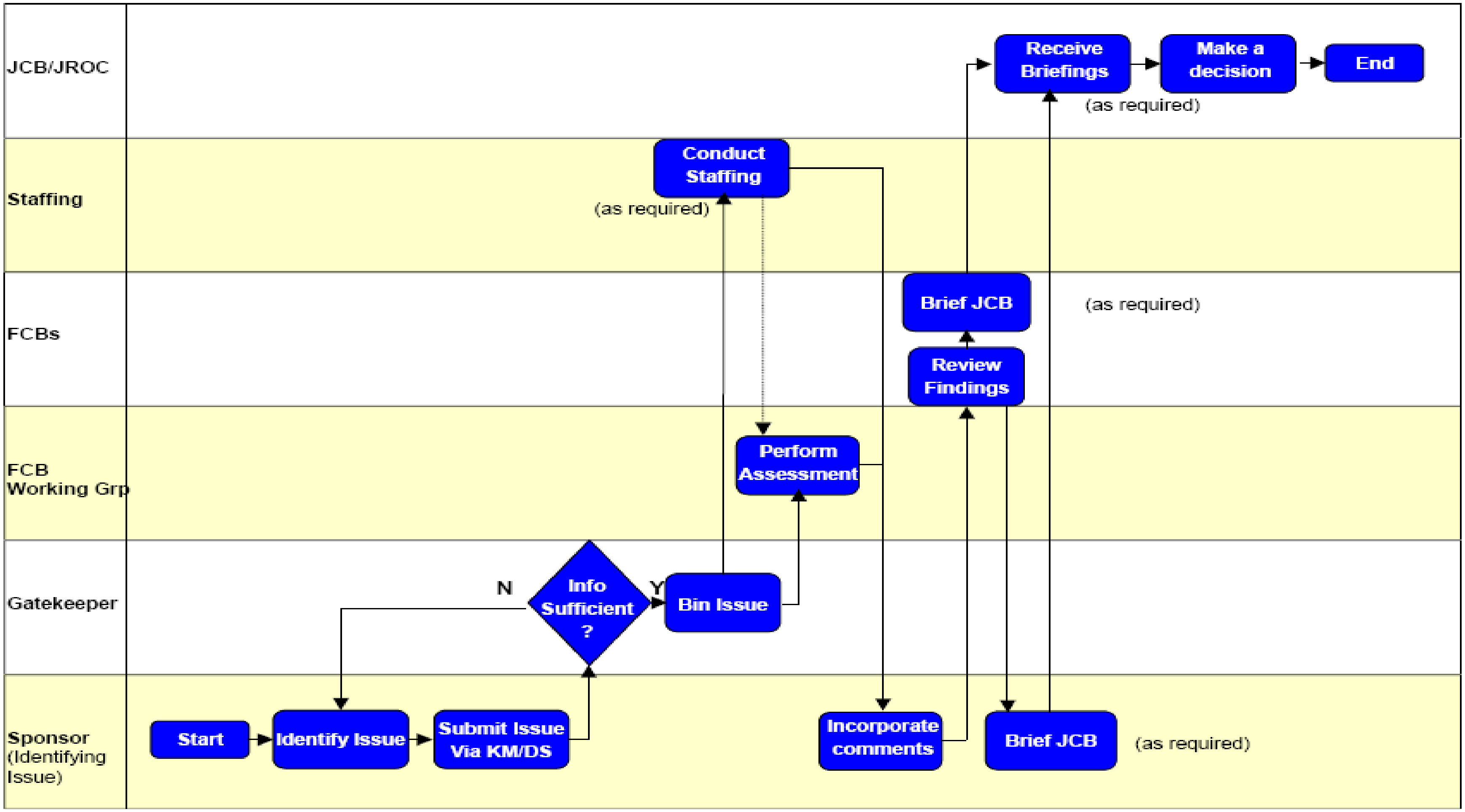

Figure 17. JCIDS and FCB.

FCB is central to JCIDS and provides Service and Functional Area representation as well as analysis of existing capabilities and future shortfalls in capabilities. FCB analysis is provided to the Joint Capabilities Board and Joint Requirements Oversight Council [From CJCSI 3137.01C, 2004].

The external agency relationship between the FCB and C4I test organizations, and the list of sub tasks needed to complete the Define Measures task, is illustrated in Figure 18.

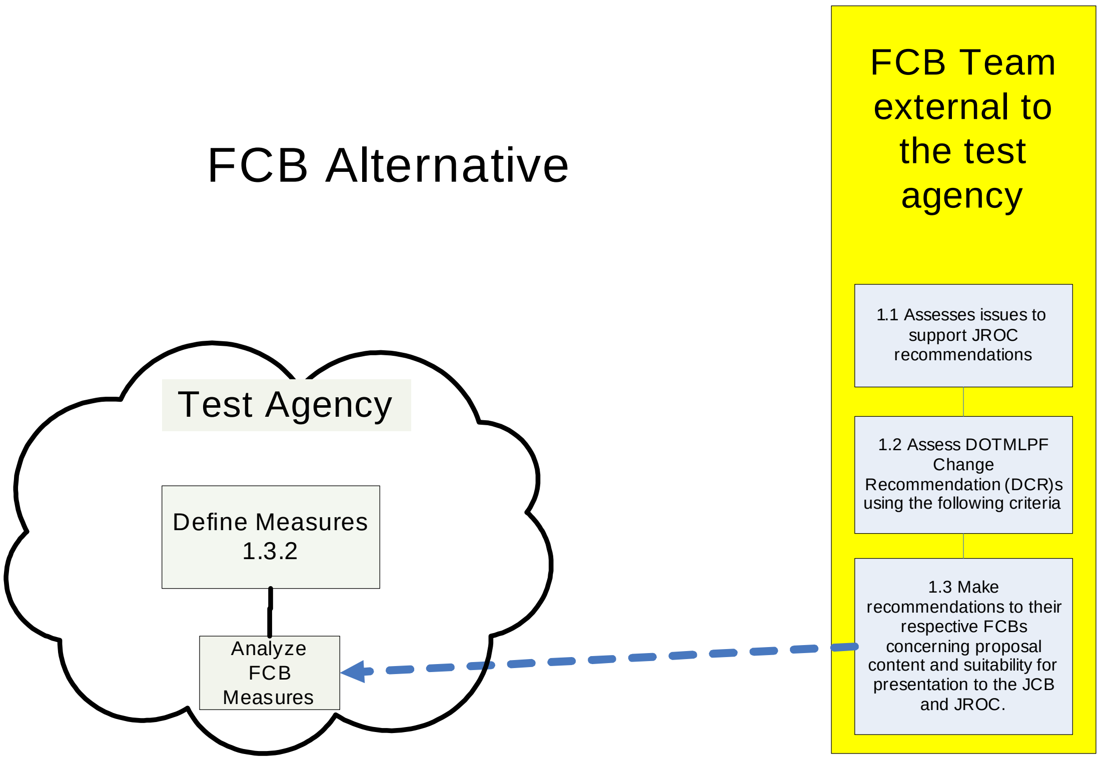

Figure 18. List of Sub Tasks needed to Complete Define Measures.

The FCB Alternative performs the task of defining measures, using a team external to the test organization that meets weekly throughout the year. Once the test agency enters their planning process for a C4I Evaluation, they elicit input from the FCB team on capability measures. These measures are analyzed for feasibility and testability before they are included in data collection and analysis.

Because the FCB is external to the test organization, some analysis of the performance measures generated by the FCB will be necessary. Figure 19 illustrates both the external nature of performance measure generation, for this alternative, as well as the required analysis performed internally to the test organization.

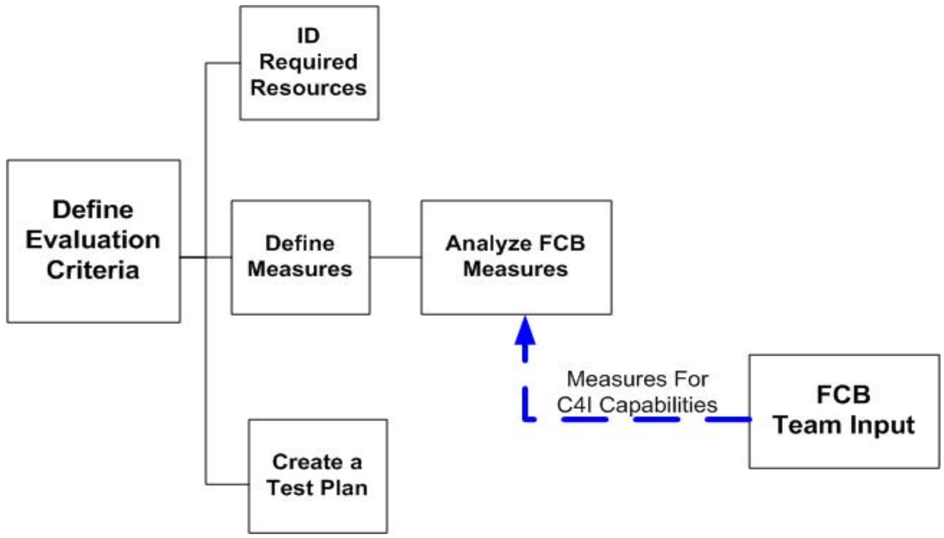

Figure 19. FCB provides external input to C4I Test Organization.

This illustration highlights that the FCB is external to the Test organization, and both organizations continuously coordinate their efforts. The FCB meets and generates performance measures independent of the test organization's schedule. From a planning perceptive; the test organization need only analyze incoming measures for feasibility and testability.

c. Differences between SCR and FCB

From the JC3M Functional Hierarchy perspective, SCR and FCB appear the same. The difference between these alternatives is in the approach each alternative takes to complete process 1.3.2 "Define Measures" in the JC3M Functional Hierarchy, as illustrated in Figure 20.

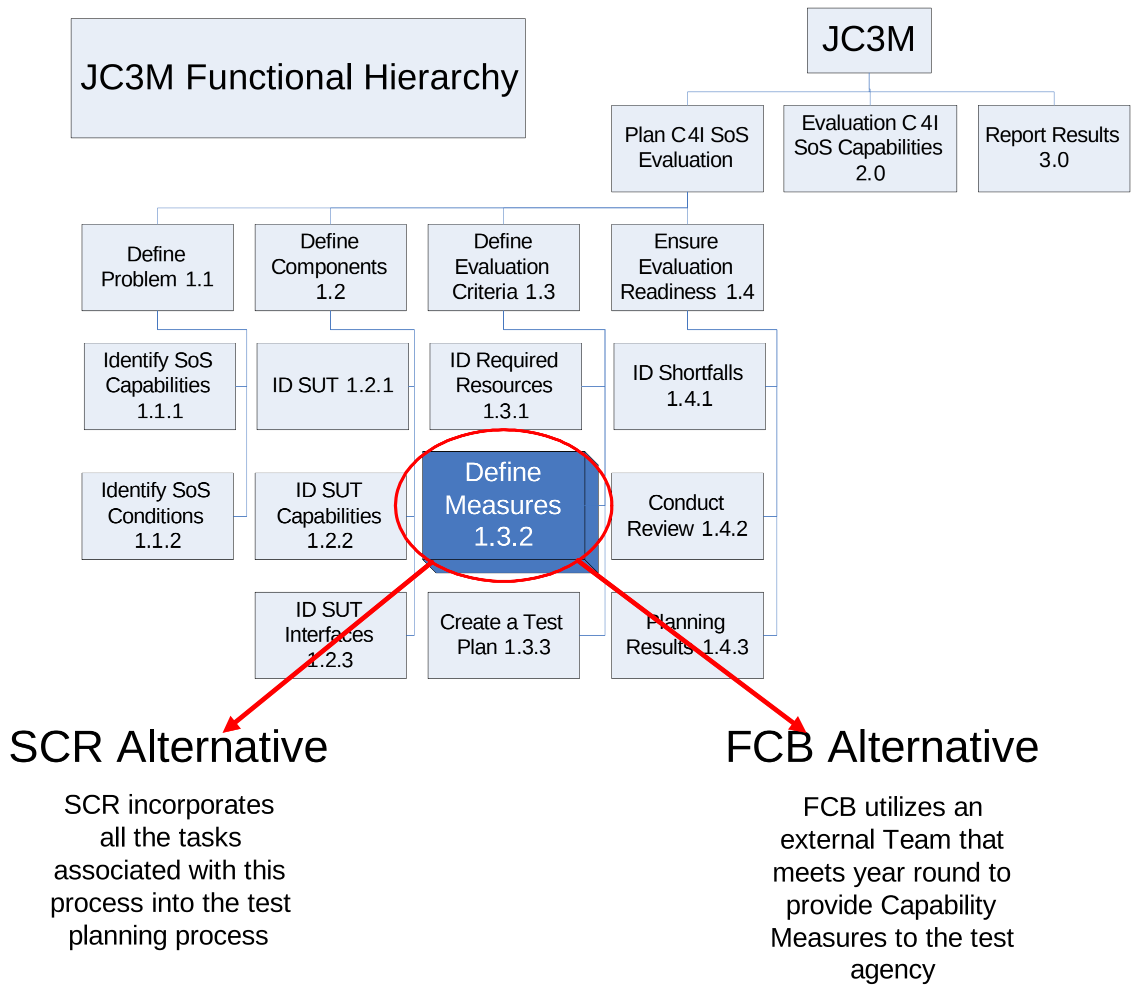

Figure 20. SCR and FCB Variance.

The FCB and SCR alternatives differ in subtasks and their approach to JC3M function 1.3.2 “Define Measures.” SCR performs this task with internal resources, and in response to requests for C4I SoS evaluation. FCB is a resource external to the C4I test organization, and performs this task weekly.

The alternatives differ in the source of personnel required to execute a C4I SoS evaluation; whether they have been used in a historical event, have been simulated, or are a new proposal; what organization chartered their development and execution; and the sources used to define performance measures. Table 5 summarizes the key similarities and differences between the alternatives.

	Personnel Resources	Used for Testing	Service or Joint	Performance Measure Creation
FEDOS	Internal	Yes	Executed by Service test organization, driven by Service stakeholders	Stakeholder agreement
MC3T	Internal	Yes[1]	Service level charter for certification of C4I capabilities	Doctrine Developers and C4I system stakeholders
JTEM CTM	Internal	No[2]	Developed for joint use	Review of doctrine, system documentation
FCB	Internal / External	No	Proposed for joint use	Review of Doctrine and system documentation by Joint C4I SME Panel
SCR	Internal	No	Proposed for joint use	Doctrine Developers and C4I system stakeholders

Table 5. Summary Comparison of Alternatives.

The table summarizes key features of the alternatives under consideration. Resources indicate if personnel used in the conduct of a C4I SoS evaluation are internal or external to the test organization. Used for Testing indicates if the alternative has been used at a test organization. [1]MC3T was projected to execute a proof of concept in October 2007. [2]JTEM CTM has executed simulations, and was projected to conduct limited-scope tests in late 2007 (results not available for review). Origin indicates the organization that ordered the development or execution of the alternative. JTEM CTM is a Joint Test and Evaluation project chartered by the Director of Operational Test and Evaluation. Source of Performance Measures indicates where performance measures are generated.

C. ALTERNATIVE SCORING CRITERIA

After the revisions to the JC3M approach, revised EM were required to rank the alternatives. The original nine EM created as part of the JC3M value hierarchy, and documented in Appendix D, were reviewed, and those specific to threshold values (Percentage of Traceable Thresholds, Number of Traceable Thresholds Identified) were eliminated. EM that measured the SoS configuration (Percentage of Capabilities Identified, Percentage of Shortfalls Identified, Number of C4I SUT, Percentage of

Interfaces Identified), rather than measuring the production of performance measures, were eliminated.

Those EM that measured how well the alternative performed (Percentage of Traceable Measures, Quality of Planning Outputs) were retained, as well as those EM that measured the duration of the alternative process (Days to Plan Evaluation). Labor Hours were retained, and though not seen below, were used in the Life Cycle Cost Estimate (LCCE) for each alternative. Finally, those EM that measured the flexibility of the alternative (Elasticity of Labor, Elasticity of Duration) were also retained. Table 6 lists the revised EM used to rank the performance of each alternative.

	Percentage of Traceable Measures	Days to Plan Evaluation	Quality of Planning Outputs	Elasticity of Labor	Elasticity of Duration
Alternatives	**1.3.2**	**1.4.3**	**1.4.3**	**4.1**	**4.1**
FEDOS					
MC3T					
JTEM CTM					
FCB					
SCR					

Table 6. JC3M Scoring Matrix.

EMs used for comparing alternatives measure traceability of outputs, duration, quality of outputs, and the response of the alternative to changes in SoS size. Labor hours were later recorded, but used in the LCCE, required for the final Cost/Benefit analysis.

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IV. MODELING AND SIMULATION

A. JC3M USES OF MODELING AND SIMULATION

Modeling and Simulation (M&S) was the most important element of the JC3M SE process, because it allowed alternative solutions to be compared in an affordable, effective, and repeatable manner. If real systems could be utilized in their operating environment, comparisons would be of higher fidelity, but this is not often possible. In many situations, safety, practicality, or resource constraints make it impossible to utilize alternatives in their proposed environment. It is not acceptable, for example, to provoke a war to test the effectiveness of a defensive system. It is also not prudent to purchase and field a system, without an acceptable estimate of performance, before the start of hostilities. The team could not build facilities and implement each alternative process for C4I SoS evaluation in order to compare their effectiveness and measure their costs, so M&S was used.

A model is a physical, visual, or mathematical representation of a real system that accounts for its known or inferred properties and may be used for further study of its characteristics [Forsberg, Mooz, Cotterman, 2000: 18]. The purpose of a mathematical model is to represent key characteristics of the real system that we want to study, such as operating cost, productivity, or time to market. The purpose of a visual model is to allow analysis of key relationships, inputs and outputs, and functional flows of the real system. Software tools were used to build both mathematical and visual models of each alternative.

Simulation operates the model with selected inputs, outputs, and environmental conditions in order to analyze the performance of the system. Models of each alternative were generated, and simulations were executed on the models utilizing different data inputs in a systematic and logical manner to gain insight into how each alternative would perform. The outputs from the models and simulators were analyzed by the team, and the results provided input into the Analysis of Alternatives phase. With the exception of the FEDOS alternative, none of the alternatives under consideration have historical performance data available for analysis; therefore modeling and simulation was an effective method to analyze the alternatives, predict behavior under varying conditions, and compare the performance of the different alternatives.

Figure 21 identifies two of the modeling and simulations used to generate three of the five EM used to compare the performance of the alternatives. POW-ER (Project, Organization, and Work for Edge Research) refers to a modeling and simulation tool developed by Stanford University to optimize the work flow of an organization. Arena refers to the Rockwell Automation tool that can model how a system behaves over time. POW-ER, Arena, and CORE (another M&S tool) are described in detail in Section B "JC3M Modeling Tools." In Figure 21, "offline evaluation" refers to the consultation with SMEs (described in Appendix C) that was used to generate the remaining EM.

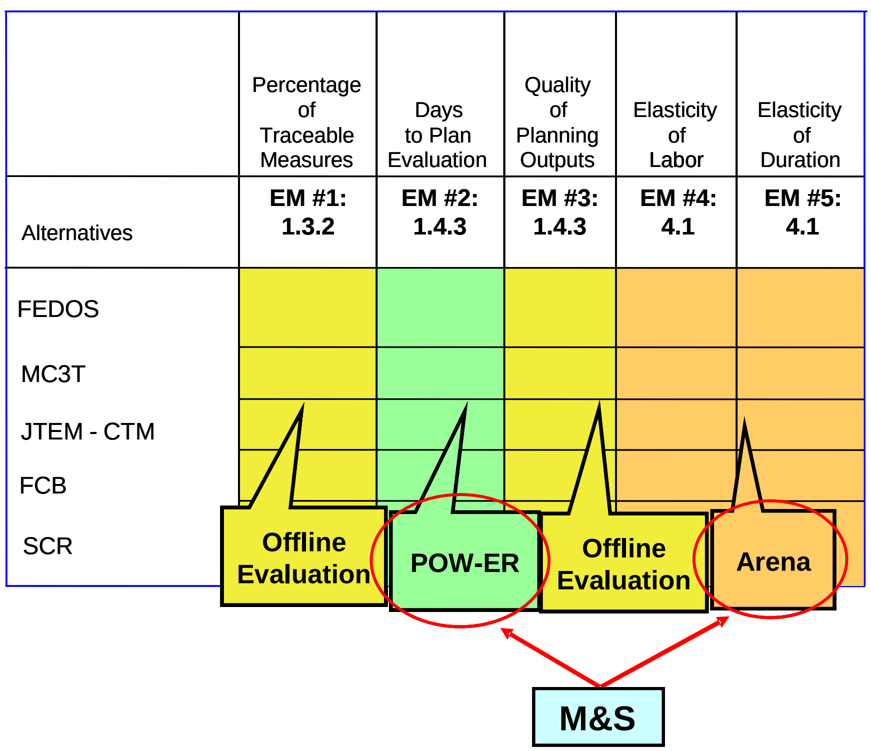


Figure 21. M&S Contribution to JC3M Scoring Matrix.

This figure illustrates the three EM which relied on M&S for data. The "offline evaluation" in the figure refers to the SME consultation described in Appendix C.

M&S enabled the team to predict the behavior of an alternative when input parameters changed. The team was able to identify what would happen if the input parameters to a system increased by 10%. Would the labor hours and calendar duration increase by the same amount? It was important to be able to answer these questions, because they provided insight into the behavior of the alternatives. The effects on duration and labor hours related directly to the elasticity of the alternative.

B. JC3M MODELING TOOLS

The M&S tools used in the project allowed the team to generate models and run simulations to analyze the required EM for each of the JC3M alternatives.

1. CORE

CORE is a systems engineering software tool that provided traceability from Problem Refinement through AoA. The team used CORE to construct standard Integration Definition for Function Modeling (IDEF0) diagrams. The IDEF0 diagrams provided the reference architecture for analysis of the alternative systems. The IDEF0 diagrams allowed the team to identify and analyze the functions that are performed by JC3M, as well as by each alternative, and to record the mechanisms (means) by which they were performed. The graphical representation of the systems provided by CORE through the IDEF0 permitted the team to conceptualize the functional requirements of the systems. IDEF0 diagrams helped to facilitate understanding, communication, consensus and validation of the systems under study [Federal Information Processing Standards Publication, 2007: 183]. Samples of the CORE IDEF0 analyses are provided in Appendix F.

2. POW-ER

POW-ER (Project, Organization, and Work for Edge Research) is a project organization modeling and simulation tool that integrates organizational and process views. POW-ER is developed as an outgrowth of the Virtual Design Team (VDT) computational modeling research at Stanford University. POW-ER addresses the organizational elements that impact the ability to work effectively, including: policies and structures (culture, communication, decisions, meetings); staffing, hiring, and training needs for workforce plans. Using POW-ER, the team modeled the organizational structure, the relationship between individuals within those organizations, and individual task allocations.

The Days to Plan Evaluation EM, identified in the M&S Contribution to JC3M Scoring Matrix (see Figure 21), is directly related to the management and organization aspect of the JC3M system. POW-ER allowed experimentation with "What-If" scenarios and provided insight into the level of rework, backlog, and risk associated with an alternative. POW-ER's ability to predict and analyze backlogs proved to be quite useful in the design and troubleshooting of alternative models, because it allowed the team to identify backlogs in the workflow of models. The analysis of backlogs in the workflow enabled the team to identify the optimized arrangement of tasks and personnel for both the SCR and FCB alternatives.

Each POW-ER model was generated by adding the tasks and personnel identified for an alternative from their respective data sets (details provided later in this chapter) Tasking flow was modeled based on the defined relationship from the data sets (i.e., parallel tasks were modeled to occur simultaneously and serial tasks were modeled to occur based on dependencies). Next, personnel that perform similar tasks were assigned into a team; those teams were then linked to a respective task.

Both parallel and serial task relationships can be seen in Figure 22, which depicts examples of each of the top level functions (Elicit Requirements, Generate Evaluation Plan, Develop Test Plans and Procedures) of the FEDOS process.

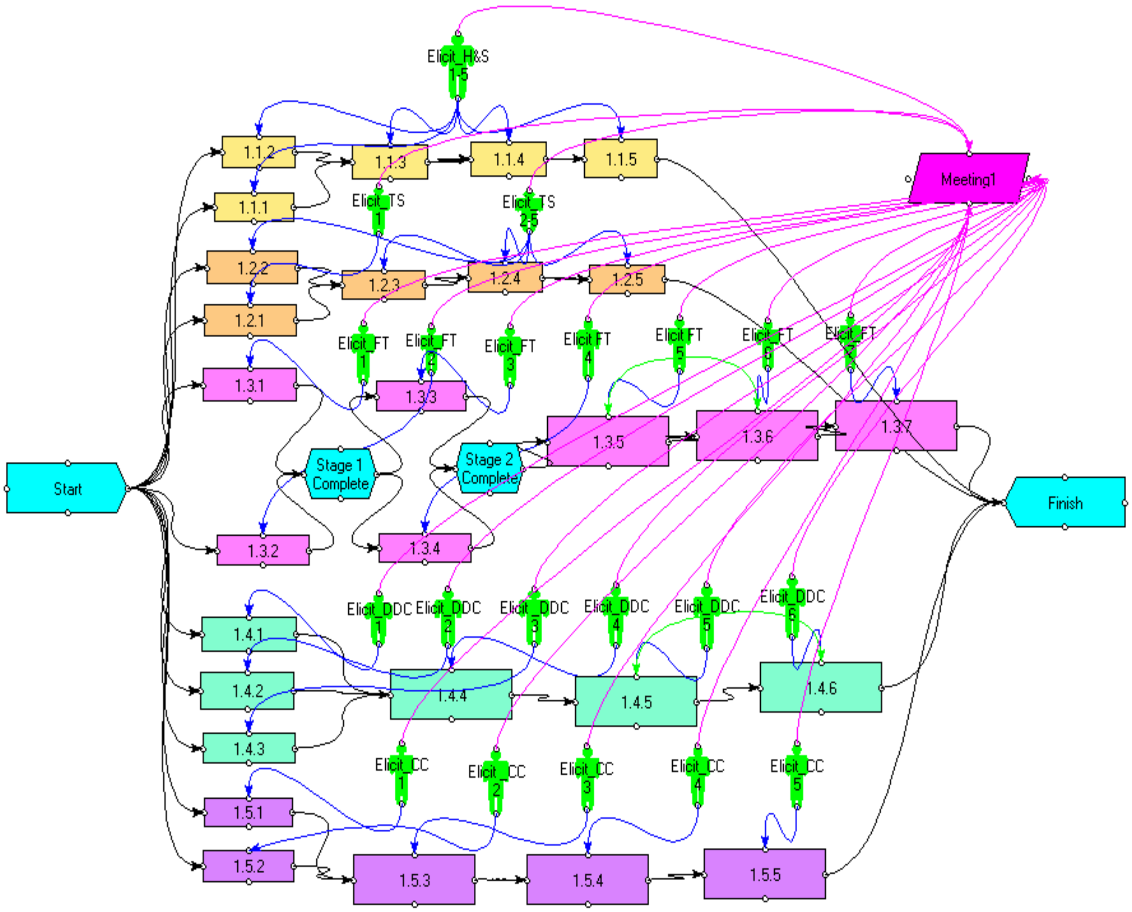


Figure 22. POW-ER Baseline Model.

Parallel and Serial tasks are modeled in POW-ER, based on historical performance (FEDOS), stakeholder input (MC3T, JTEM CTM) or design of the alternative (FCB, SCR). Models contain both tasks and personnel assigned to the tasks.

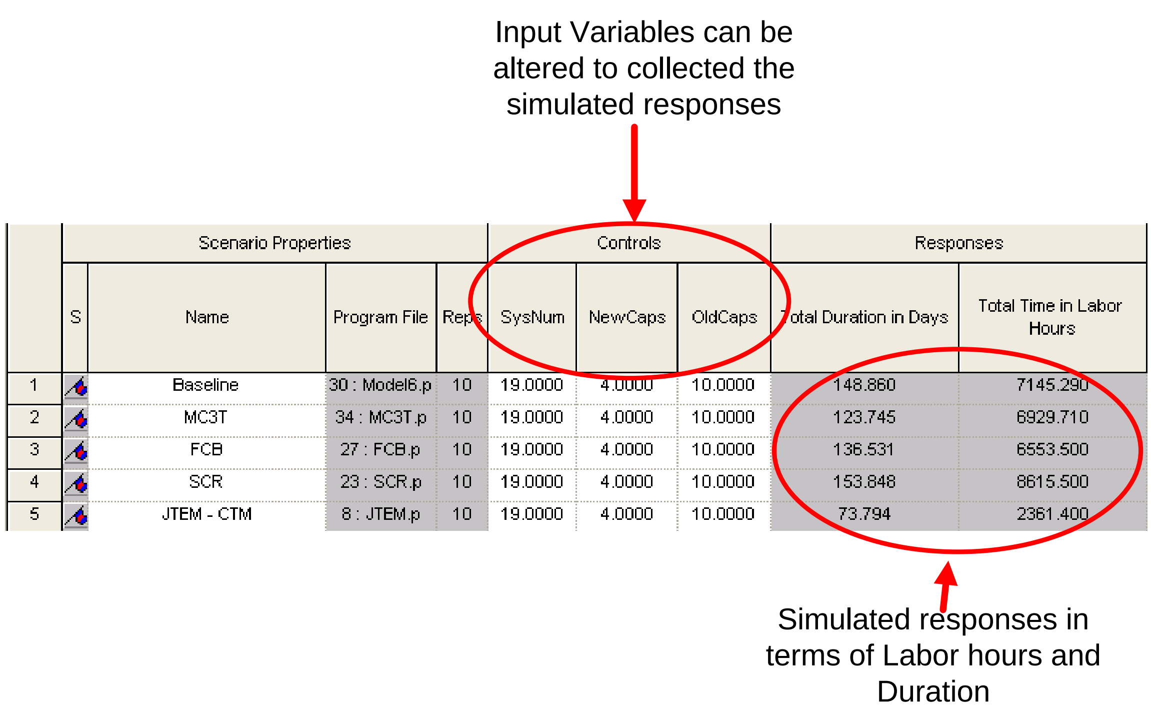
Within POW-ER, the Effort attribute for each task was set by assigning it to the duration in days identified in an alternative's data set. For the Team attribute, the Full Time Equivalent (FTE) attribute was set equal to the total hours an alternative team spent on each task divided by 40 hours (one work week).

It is important to mention that the POW-ER simulation tool calculates a task's duration in one of two ways: simulated duration or Critical Path Method (CPM). Simulated duration factors in the "hidden works" that the CPM does not. The "hidden works" associates an amount of rework and delays into each task. The simulated duration was selected for Days to Plan Evaluation EM, because it is fair to assume that these hidden works are always part of each task. The accuracy of the POW-ER model was validated against historical performance data (details provided later in this chapter).

3. ARENA

Arena provided a numerical evaluation of a system by imitating the system's operations or characteristics over time. Arena allowed the team to conduct numerical experiments in order to predict the behavior of an alternative given a set of conditions. The JC3M Scoring Matrix identifies two EM (see Figure 21) that required evaluation of the changes in output as a function of the changes in inputs: Elasticity of Labor and Elasticity of Duration. Arena allowed the team to run simulations on the alternative models with varying set of inputs; Arena displayed the output changes that corresponded to each of the varying inputs.

Figure 23 shows results of a simulation run in Arena that predicts the duration and labor hours require for planning a SoS evaluation. As noted, controls can be varied.



	Scenario Properties				Controls			Responses	
	S	Name	Program File	Reps	SysNum	NewCaps	OldCaps	Total Duration in Days	Total Time in Labor Hours
1		Baseline	30 : Model6.p	10	19.0000	4.0000	10.0000	148.860	7145.290
2		MC3T	34 : MC3T.p	10	19.0000	4.0000	10.0000	123.745	6929.710
3		FCB	27 : FCB.p	10	19.0000	4.0000	10.0000	136.531	6553.500
4		SCR	23 : SCR.p	10	19.0000	4.0000	10.0000	153.848	8615.500
5		JTEM - CTM	8 : JTEM.p	10	19.0000	4.0000	10.0000	73.794	2361.400

Figure 23. Arena Simulation Run.

Simulation allowed the team to change input parameters to reflect the concerns of stakeholders. Outputs were measured, in response to input changes, to analyze the performance of the alternatives in changing situations.

The team created a baseline C4I SoS to use in comparing the performance of each alternative in Arena (See Section C "Select a Baseline" and Section D.1 "Baseline C4I Architecture" for details of the baseline C4I SoS). After the models of alternatives were created (see Section C.7 "Build POW-ER, Arena, and CORE Model for each Alternative"), Arena was used to calculate the duration of each task. Systematic variations to the inputs (number of individual systems and number of capabilities) were made to analyze how changes in the size of the C4I SoS affected the EM of interest. From the varied inputs, and resulting outputs, the elasticity EM needed for the AoA was calculated.

All Arena models are based on data sets containing process tasks, job billets, and hours worked. For process tasks that contained sub-processes, the team created sub models as illustrated in Figure 24.

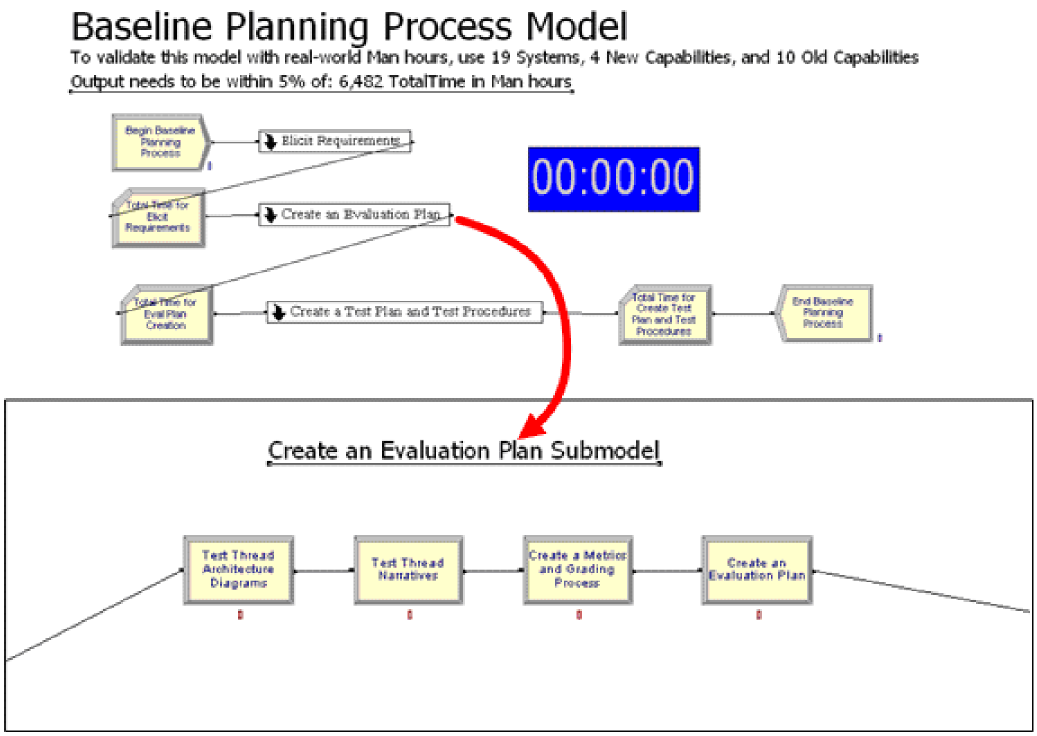


Figure 24. Example of Arena Sub-Models and Sub-Processes.

Each alternative's Arena model had sub-models that contained a series of process delays that affected Duration and Total Labor hours. The number of sub-models and associated tasks depended on the design of the alternative.

The sub models used in Arena contain process delays, as appropriate, which were used to represent average labor hours per variable instance. Figure 25 illustrates variables, units, and the mathematical expression used in calculating an example process delay.

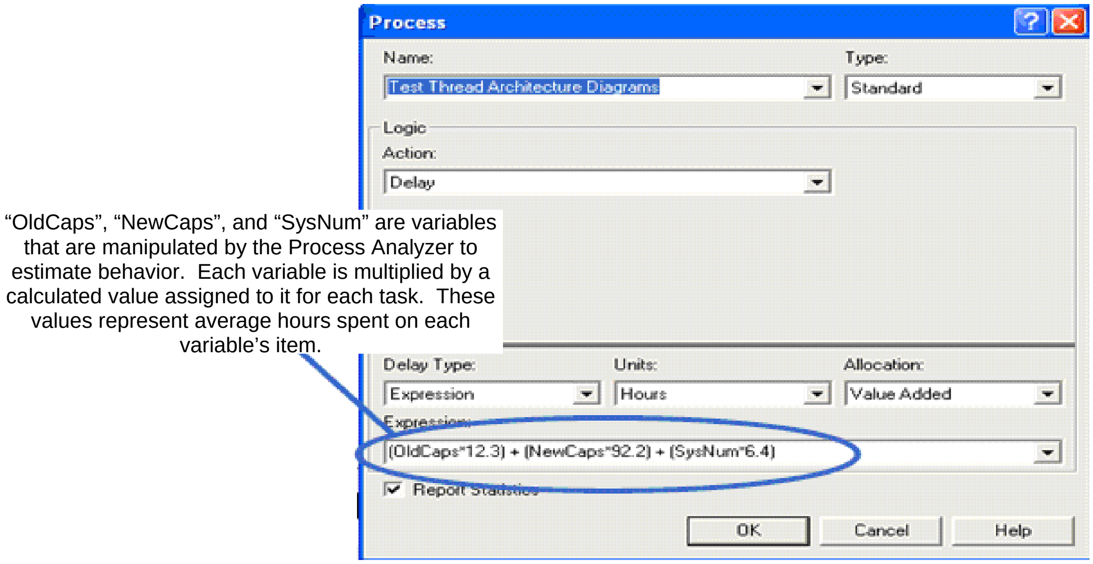


Figure 25. Example of a Process Delay Setting.

Each sub model contained a series of process delays used to represent labor hours per variable instance. The variables identified (*OldCaps*, *NewCaps*, and *SysNum*) were called and varied in a centralized process analyzer which enabled the modeling team to run multiple variations of each alternative.

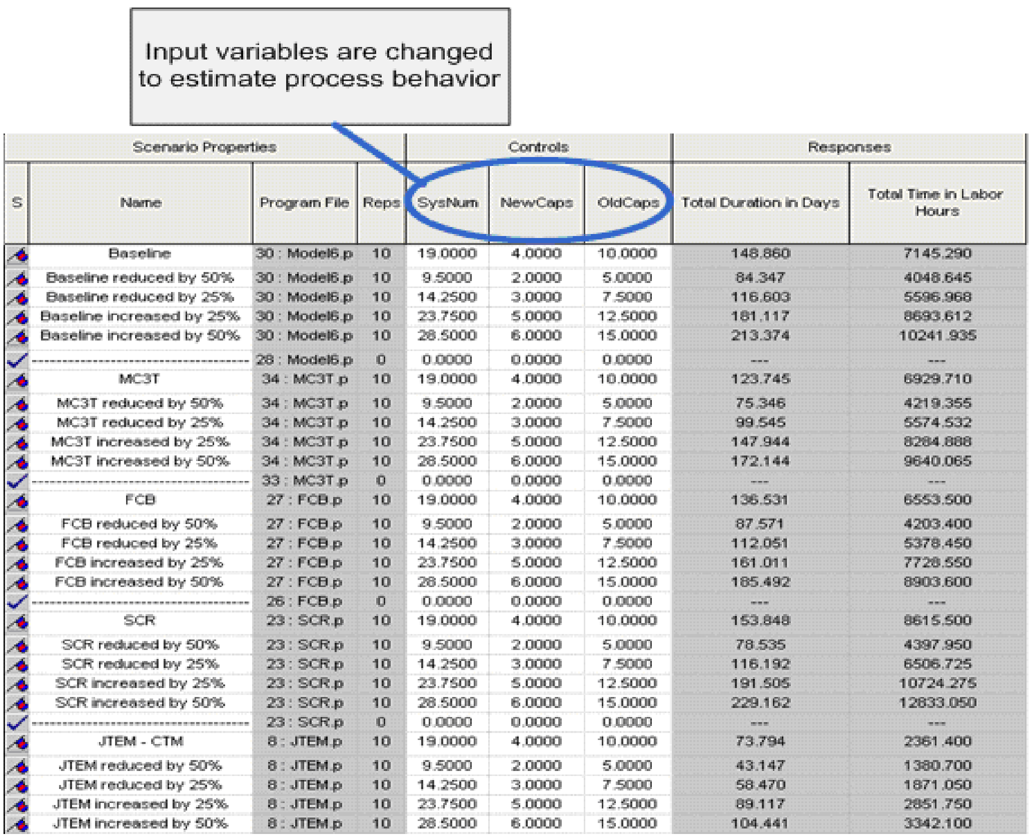
Each alternative was modeled in Arena, and imported into the Arena Process Analyzer for efficient simulation of the alternative using varied inputs. The team utilized the control feature to centrally control and vary input variables to study the associated variability of outputs. Each model used three critical input parameters to determine the size and the scale of the test event. These parameters are:

- Number of Systems (*SysNum*) – This parameter did not represent the number of instances of a system (i.e., 14 AFATDS terminals), but represented the number of types of systems under test. If the SoS contained PLI systems, communication systems, and fire control systems, *SysNum* equaled 3.

- Number of New Capabilities (*NewCaps*) – This parameter represented the number of SoS capabilities under evaluation. If the C4I test organization had little to no experience with this capability, it was considered a new capability.

- Number of Old Capabilities (OldCaps) – This parameter also represented the number of SoS capabilities under evaluation. If the C4I test organization was familiar with and had tested the capability, it was considered an Old Capability. This parameter addressed the concept of efficiency associated with experience.

Figure 26 shows a view of the Process Analyzer tool, and illustrates the multiple versions of each alternative and the varying magnitudes of *NewCaps*, *OldCaps*, and *SysNum.*



Scenario Properties				Controls			Responses	
S	Name	Program File	Reps	SysNum	NewCaps	OldCaps	Total Duration in Days	Total Time in Labor Hours
	Baseline	30 : Model6.p	10	19.0000	4.0000	10.0000	148.860	7145.290
	Baseline reduced by 50%	30 : Model6.p	10	9.5000	2.0000	5.0000	84.347	4048.645
	Baseline reduced by 25%	30 : Model6.p	10	14.2500	3.0000	7.5000	116.603	5596.968
	Baseline increased by 25%	30 : Model6.p	10	23.7500	5.0000	12.5000	181.117	8693.612
	Baseline increased by 50%	30 : Model6.p	10	28.5000	6.0000	15.0000	213.374	10241.935
	--	28 : Model6.p	0	0.0000	0.0000	0.0000	---	---
	MC3T	34 : MC3T.p	10	19.0000	4.0000	10.0000	123.745	6929.710
	MC3T reduced by 50%	34 : MC3T.p	10	9.5000	2.0000	5.0000	75.346	4219.355
	MC3T reduced by 25%	34 : MC3T.p	10	14.2500	3.0000	7.5000	99.545	5574.532
	MC3T increased by 25%	34 : MC3T.p	10	23.7500	5.0000	12.5000	147.944	8284.888
	MC3T increased by 50%	34 : MC3T.p	10	28.5000	6.0000	15.0000	172.144	9640.065
	--	33 : MC3T.p	0	0.0000	0.0000	0.0000	---	---
	FCB	27 : FCB.p	10	19.0000	4.0000	10.0000	136.531	6553.500
	FCB reduced by 50%	27 : FCB.p	10	9.5000	2.0000	5.0000	87.571	4203.400
	FCB reduced by 25%	27 : FCB.p	10	14.2500	3.0000	7.5000	112.051	5378.450
	FCB increased by 25%	27 : FCB.p	10	23.7500	5.0000	12.5000	161.011	7728.550
	FCB increased by 50%	27 : FCB.p	10	28.5000	6.0000	15.0000	185.492	8903.600
	--	26 : FCB.p	0	0.0000	0.0000	0.0000	---	---
	SCR	23 : SCR.p	10	19.0000	4.0000	10.0000	153.848	8615.500
	SCR reduced by 50%	23 : SCR.p	10	9.5000	2.0000	5.0000	78.535	4397.950
	SCR reduced by 25%	23 : SCR.p	10	14.2500	3.0000	7.5000	116.192	6506.725
	SCR increased by 25%	23 : SCR.p	10	23.7500	5.0000	12.5000	191.505	10724.275
	SCR increased by 50%	23 : SCR.p	10	28.5000	6.0000	15.0000	229.162	12833.050
	--	23 : SCR.p	0	0.0000	0.0000	0.0000	---	---
	JTEM - CTM	8 : JTEM.p	10	19.0000	4.0000	10.0000	73.794	2361.400
	JTEM reduced by 50%	8 : JTEM.p	10	9.5000	2.0000	5.0000	43.147	1380.700
	JTEM reduced by 25%	8 : JTEM.p	10	14.2500	3.0000	7.5000	58.470	1871.050
	JTEM increased by 25%	8 : JTEM.p	10	23.7500	5.0000	12.5000	89.117	2851.750
	JTEM increased by 50%	8 : JTEM.p	10	28.5000	6.0000	15.0000	104.441	3342.100

Figure 26. Screen Shot from the Arena Process Analyzer.

Arena Process Analyzer is used to centrally vary input variables for each alternative model in order to examine the effects on the performance of the alternative. In this illustration, the alternatives are identified in the left column, with sizes varied by 25% steps. This data is used, in turn, to conduct analysis of the performance of each alternative.

C. MODELING AND SIMULATION APPROACH

The JC3M team implemented an eight step M&S approach. The details of this approach are provided for clarification.

1. Select a Baseline System

A baseline of system performance was selected that could be used to validate the models created by the team. The team chose the FEDOS alternative for designing and validating performance models of all alternatives. Use of FEDOS allowed the team to compare the performance from M&S tools to the historical data documenting the actual performance of FEDOS, thus validating the accurate performance of the model.

Inputs such as number of systems, capabilities, and tasks were gathered from the historical record, models were designed, and simulation outputs were generated. Outputs were compared to actual results, and the model was systematically adjusted until it produced results that were close to actual labor hours and duration (Days to Plan evaluation) of the historical event. The labor hour calculations were validated to within ±1% of historical values because this data was used was used to calculate the LCCE of the alternatives. Duration was validated to within ±4% of historical values because this EM only contributed 5.8% to the overall performance score (see Chapter VI, Section E "Analytical Hierarchy Process") of the alternative. This provided the team confidence that the models built in Arena and POW-ER accurately emulated the performance of the FEDOS alternative, and could be used to accurately simulate the performance of other alternatives.

As noted earlier, each of the five alternatives focused on the planning of a C4I SoS evaluation. Figure 27 illustrates the Planning function of JC3M.

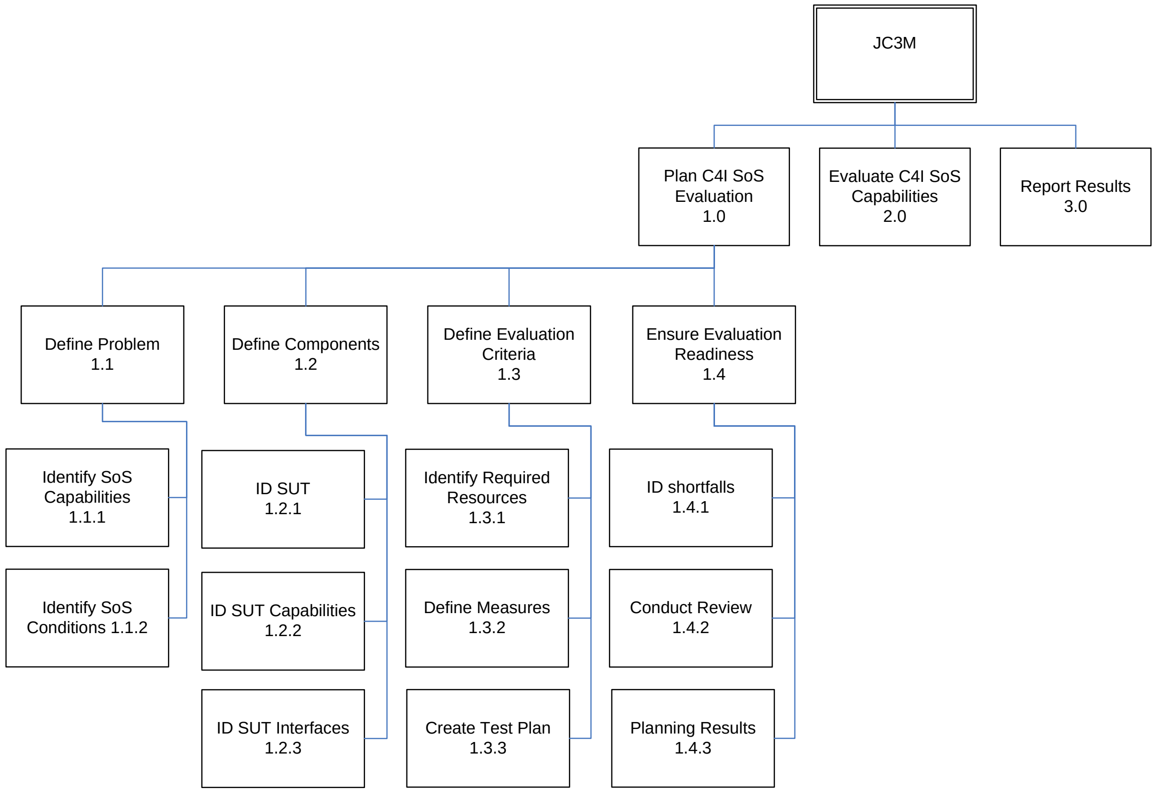


Figure 27. JC3M Planning Functions.

The models of alternatives were validated by comparison to FEDOS historical performance. After adjustment of the models to produce results within 1% of historical FEDOS performance, each of the alternatives was modeled in turn. This illustrates the entire planning functional hierarchy of JC3M; Figure 11 only illustrates the critical EM.

2. Select a Candidate C4I Test Architecture as a Baseline SoS

The JC3M team selected the C4I SoS architecture tested in 2005, using the FEDOS process, as stated above, because historical performance data existed which allowed consistent comparison of the models to actual results. The architecture that was the subject of the FEDOS 2005 Event was composed of nineteen different types of systems (described in Section D “Baseline Model Development” of this chapter). The test evaluated fourteen SoS capabilities; ten were previously tested (“old”) and four were new to the test team (“new”). Each of the alternatives was modeled with this architecture as the C4I SoS under evaluation.

This consistency of C4I SoS under evaluation is important because the FEDOS 2005 was a real SoS evaluation event that could be modeled and simulated. The results of simulation could be compared to historical performance data. Further, establishment of a baseline C4I SoS allowed for an “apples to apples” comparison of the performance of each alternative, as they were used to plan the evaluation of the same C4I SoS.

3. Assemble a Data Set for the FEDOS System

A data set is the compilation of data (duration of tasks, resources, sequence of events, labor hours) used to populate the model. In this case, historical documents that recorded the performance of FEDOS 2005 were used as the sources of data that documented the configuration of the baseline system. Three historical documents were used to build the baseline data set.

The FEDOS 2005 Technical Support Plan (TSP) was a Microsoft Project® plan that specified the tasks performed and the order in which they were performed; identified the resources used for each task; and identified serial task dependencies and parallel tasks [Manning (b), 2005]. The Labor Hours report [Manning (a), 2005] recorded the hours worked by each employee for each task. The Test Report [Marine Corps Tactical Systems Support Activity, 2005] provided the evaluation of the conduct of FEDOS in 2005. Figure 28 provides an illustration of the process of conversion of historical data into the baseline data set.

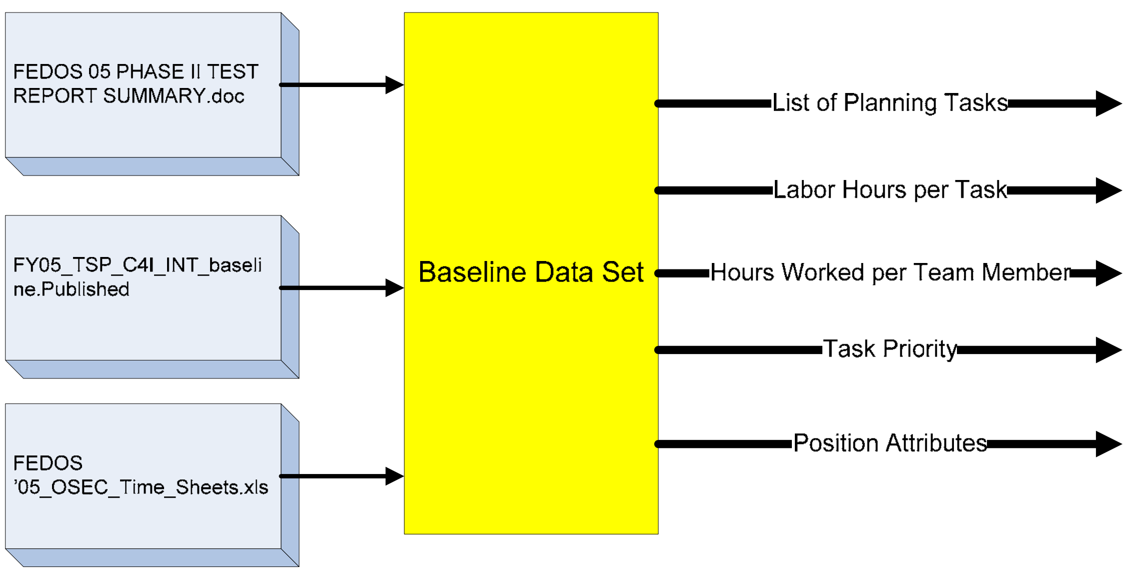


Figure 28. JC3M Baseline Data Set Inputs and Outputs.

The baseline data set was built from three historical records, and was used to populate the models of each alternative in turn. This allowed validation of the models against historical data, as well as evaluation of the performance of each alternative against the same size and scope C4I SoS.

Data from the TSP, Labor Hours Report, and Test Report were summarized in a spreadsheet that consisted of the following list of data for use by the models of each alternative:

- a comprehensive list of planning tasks used for test planning,
- labor hours for each test team member (per task),
- calendar duration for the planning process,
- inputs and outputs for each task,
- each test team member's cost per hour,
- test team position such as Test Lead, or Technical Writer, and
- organizational attributes such as duration of work day, duration of work week.

4. Model, Simulate, and Validate the Baseline Processes

In this step, a model of one alternative, (FEDOS) was created from the baseline data set in POW-ER, ARENA and in CORE. (A model of each of the other four alternatives is created in step 7.) Figure 29 illustrates the data set inputs to each modeling tool and the outputs from the simulations.

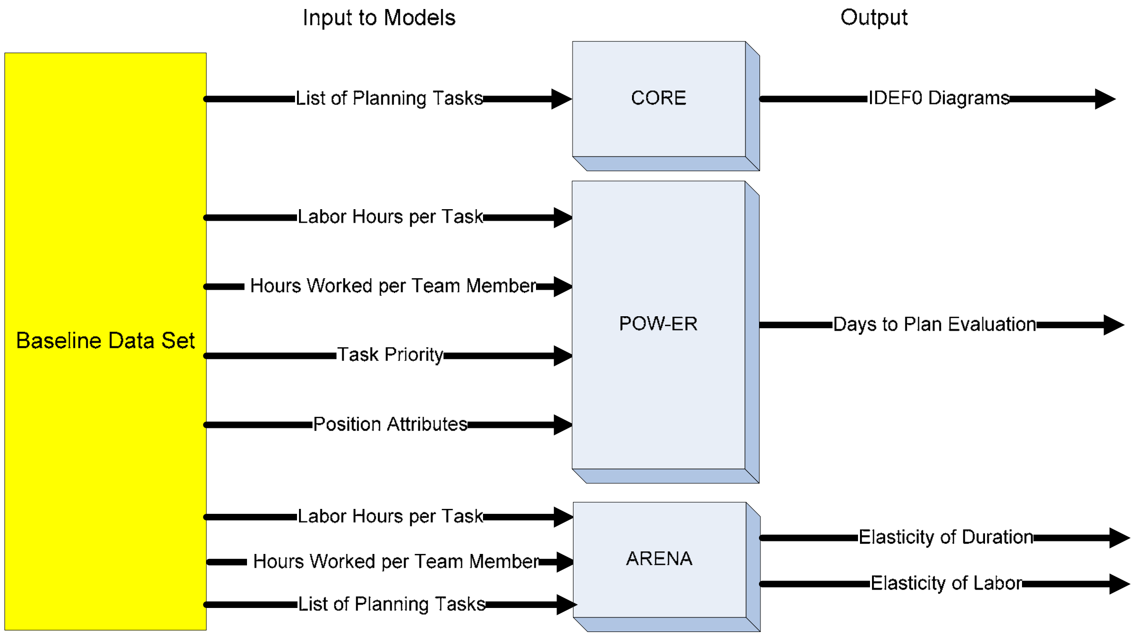


Figure 29. Input and Output of Baseline M&S.

CORE provided IDEF0 Diagrams for functional analysis (see Appendix F). POW-ER provided Days to Plan Evaluation. Arena provided labor hours (used for Life Cycle Cost Estimate) and Elasticity of Labor and Duration for each alternative.

5. Map the Alternatives to the Baseline Processes

Each task in each of the alternative tasks was mapped (where possible) to the baseline processes. This allowed the test team to use known labor hours and cost from the baseline to complete an estimation of cost and duration for alternative. Figure 30 shows some of the tasks from the baseline and their mapping to the JC3M functional hierarchy.

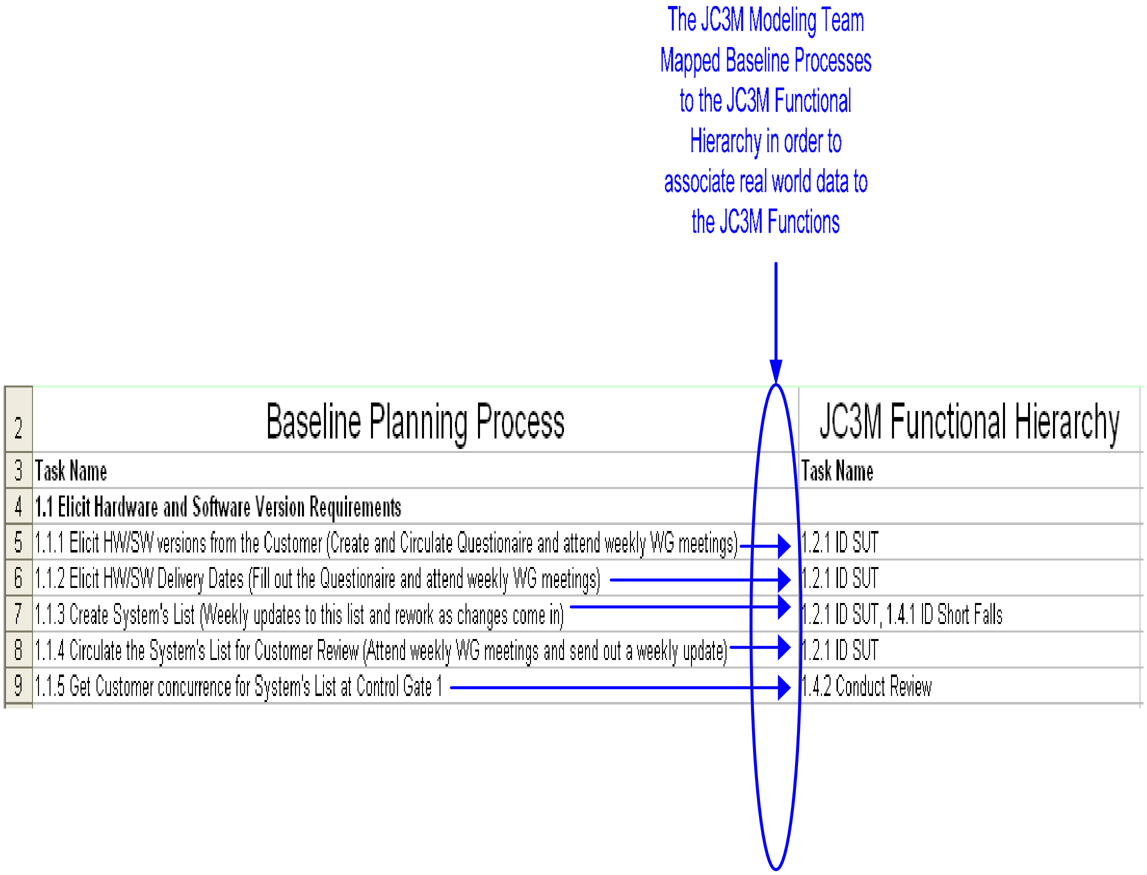


Figure 30. Mapping of Baseline Tasks to JC3M.

This figure illustrates the traceability of tasks to the JC3M Functional Hierarchy. In the figure, processes from the baseline are mapped to JC3M tasks. Because many tasks were common from alternative to alternative, baseline tasks could be mapped to each alternative model, ensuring consistency of comparisons, traceability of inputs and outputs, and reducing variability.

6. Create Data Sets for Each JC3M Alternative

After the mapping was complete, each alternative's data sets were assembled from the baseline data. Each alternative's tasks and sub-tasks were mapped as close as possible to baseline data. The duration and labor hours were assigned based on this actual data. If an alternative had tasks that did not map to the baseline, MCTSSA SME input was used to estimate and validate duration and labor hours.

7. Build POW-ER, ARENA, and CORE Model for Each Alternative

In step 4 a POW-ER, Arena, and CORE model was developed for the Baseline. In step 7 a model of each of the remaining four alternatives was developed in each of the three modeling tools. Figure 31 depicts a high level view of this step.

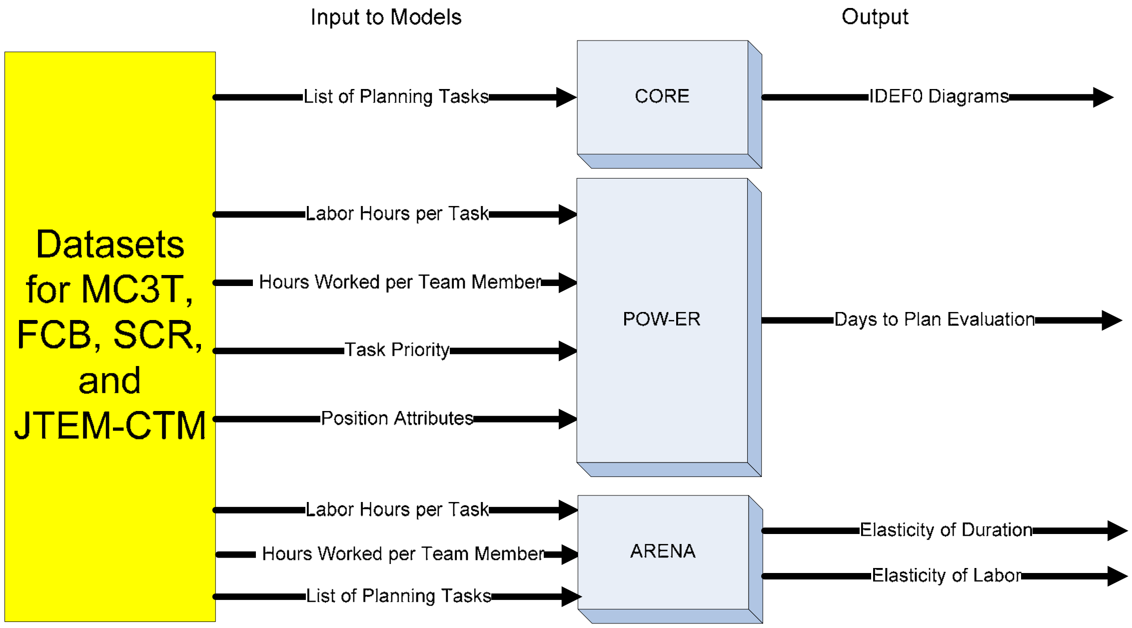


Figure 31. Input and Output of Alternative M&S.

This is a diagram of Alternative inputs to CORE, POWER, and ARENA, and their associated simulation results.

8. Run the Models and Capture Simulation Results

Each POW-ER model was run to generate the *Days to plan an evaluation* EM. For each ARENA model, simulations were run to generate Elasticity *of Labor* and *Elasticity of Duration* EM. Each CORE model generated *IDEF0 diagrams*.

D. BASELINE MODEL DEVELOPMENT

Each JC3M alternative system represented test planning processes. In order to compare each alternative's performance, each model's parameters must be consistent in terms of *number of systems under test* and *number of capabilities under test*.

1. Baseline C4I Architecture

The team elected to model the C4I SoS that was under test during the FEDOS 2005 test event as the baseline system. This C4I SoS was selected because it had had complete employee time sheets, a project schedule, and the TSP data that recorded the cost associated with the planning process. This data gave the team valuable insight actual labor hours, duration, and cost to plan a SoS test event. The architecture for the FEDOS 2005 event SoS consisted of ninety-one physical systems comprised of nineteen types under test, as listed in Table 7.

Systems	Software / Firmware Version	Hardware Version
AFATDS	6.4.0.0_UMR_92Z	CCU2/Tadpole
CLC2S	2.0.5	T-40
CONDOR	3.6.5.0.0.9	N/A
DDACT	4.0.0.0.12D	RPDA 5500
ENM	4.4	CF28
EPLRS	11.4	RT-1720
GCCS-J	4.0.1.0	Netra 240
GCCS-J Client	4.0.1.0	T-40
IOS V1	4.0.1.1.01	Netra 240
IOS V2 (Apps)	3.7.0.1.01	Netra 240
IOS V2 (SDS)	3.7.0.1.01	Netra 1125
IOW V1	4.0.1.1.07	T-40
IOW V2	3.6.6.1.01	T-40
MDACT	3.6.5.0.12 Final	RHC 31A
PFED	1.0	RPDA 5500
SINCGARS	N/A	RT-1523A, RT-1523B, RT-1523E
SISTIM	6.4	CCU2
TBMCS Lite	1.1	Sunfire
TBMCS Remote	1.1	T-40

Table 7. Systems Under Test during FEDOS 2005.

The architecture for the FEDOS ’05 SoS evaluation consisted of nineteen types of C4I systems. Ninety-one physical systems were utilized in the test. Both system types and physical systems were utilized based on stakeholder request, doctrine, and equipment availability.

The systems architecture was based on doctrine, requests by stakeholders, and equipment availability at MCTSSA. Figure 32 is a diagram of a similar C4I SoS architecture, used for MC3T, in a 2007 test event.

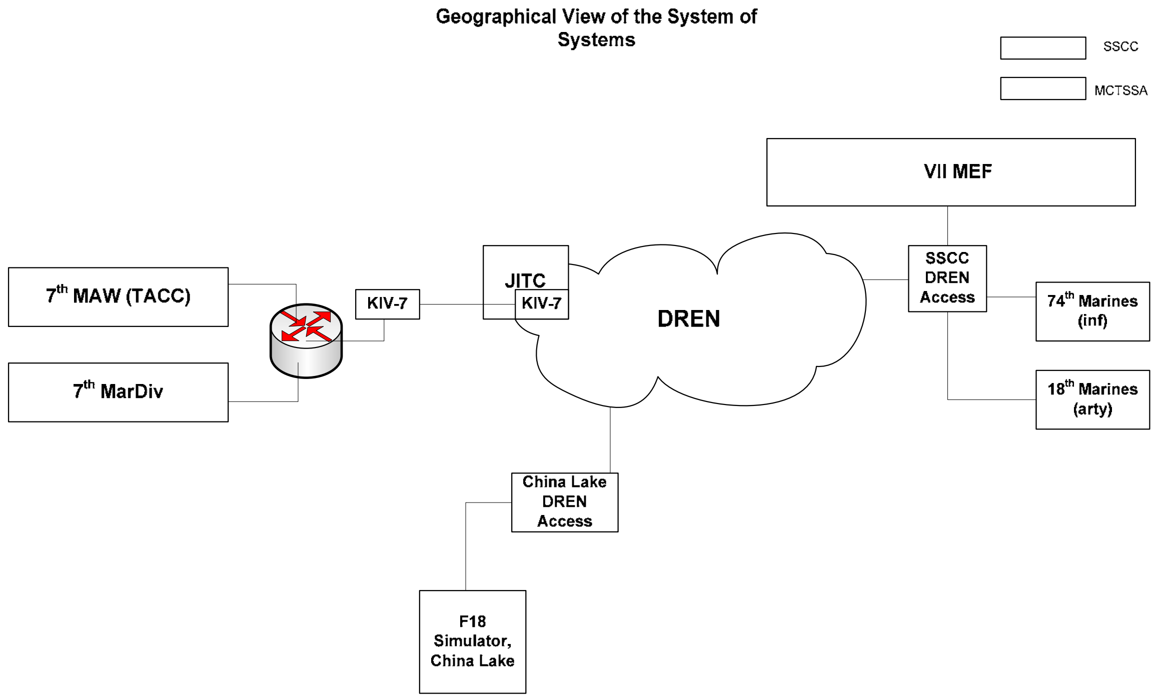


Figure 32. Representative C4I SoS Architecture.

This illustration depicts the echelons of command seen in a representative C4I SoS test event, as well as connectivity between nodes. Green nodes represent notional Marine Air Wing and Marine Infantry Division elements at JITC. Yellow nodes represent notional Marine Expeditionary Force, Infantry Division, and Artillery Regiment elements at MCTSSA. The blue node represents a simulated aircraft at Naval Air Warfare Center (NAWC) China Lake. The white cloud represents connectivity through the Defense Research and Engineering Network to remote sites.

2. Baseline System of System Capabilities

SoS capabilities are capabilities that are achievable by multiple systems working together as a whole, but are not achievable by a single system working on its own. The FEDOS 2005 test event included fourteen capabilities. Table 8 lists the fourteen SoS capabilities tested.

3. Defining "Old" versus "New" Capabilities

The Arena models included a function to model the effort required to plan a C4I SoS with both "Old" and "New" capabilities. In this context, an "Old" capability is one that has been previously evaluated by the test organization. The distinction between "Old" and "New" allowed the simulation of the effects of learning over time. The test organization familiar with a capability may have been able to reuse previous or modify previous work products. For a "New" capability, the test organization had no reusable work products, and may have required some training to exercise the capability correctly.

As a result, new capabilities historically take longer to prepare for, regardless of the systems involved.

SoS Capability	Description
Blue Position Location Information (Blue PLI)	This capability exercises the SoS ability to receive and display all updated unit positions for maintaining the Blue Force Common Operational Picture (COP)
Close Air Support (CAS)	This capability exercises the SoS ability to introduce a Joint Tactical Air Request (JTAR) into the SoS, approve a mission, and route that mission between AFATDS and TBMCS
Call for Fire (CFF)	This capability exercises the SoS ability to transmit a Fire Request from a Portable Forward Entry Device (PFED) to an Artillery battery via AFATDS.
Red Track Processing	This capability exercises the SoS ability to use MAGTF intelligence systems to process and fuse enemy location (Red Track) information
Time Sensitive Targeting (TST)	****NEW**** This capability exercises the SoS ability to use Fires and Intelligence systems to process a Mission Report.
Air Tasking Order (ATO)	This capability exercises the SoS ability to generated and disseminated an ATO throughout the AFATDS network to each Effects Management Tool (IOW V1) using the MEB TBMCS Lite
Battlefield Geometry Exchange (BGE)	This capability exercises the SoS ability to exchange Battlefield Geometries and Overlays between the IOS V1 and AFATDS
Common Logistics	****NEW**** This capability exercises the SoS ability to pass logistic requests between MEB and RLT CLC2S Server in untethered mode
EPLRS Time Slot (ETS)	This capability exercises the SoS ability to compare the network utilization of the EPLRS 2ms and 4ms time slots. Based on network load
COP Synch Tools (CST)	This capability exercises the SoS ability to disseminate tracks within the Global Command and Control System (GCCS) architecture, validating that the GCCS - Joint (GCCS-J), IOS V1, and GCCS-COP (Unit Operations Center) synchronized their databases.
Filters and Permissions	****NEW**** This capability exercises the SoS ability to filtered track information utilizing Geo-filters.
Message Exchange (ME)	This capability exercises the SoS ability to successfully passed Internet Relay Chat and Veriable Message Format (VMF) messages between company, battalion, and regiment.
Overlay Exchange	This capability exercises the SoS ability pass VMF K05.17 overlay files message within the Command and Control Personal Computer (C2PC) network.
Theatre Ballistic Missile (TBM)	****NEW**** This capability exercises the SoS ability to generate a missile track for dissemination throughout the CST and C2PC gateways.

Table 8. SoS Capabilities Tested during FEDOS ’05.

This table lists the 10 old and 4 new SoS capabilities used, at various command echelons, in the FEDOS 2005 test event. The capabilities used in the test were defined based on stakeholder requirements, doctrine, and equipment availability.

E. SIMULATION RESULTS

1. Arena Simulation Results

Elasticity – "A measure of responsiveness. The responsiveness of behavior measured by variable Z to a change in environment variable Y is the change in Z observed in response to a change in Y." [About.com, 2007].

Arena was used to calculate elasticity for each of the alternatives. In order to accomplish this, the team captured the percent change in output (*Variable Z*) divided by percent change in input (*Variable Y)*. To vary the input, the team increased or decreased the input variables (Number of Systems, Number of New Capabilities, and Number of Old Capabilities) in 25% increments and recorded the resulting output variables (duration and total labor hours). From the baseline of 10 old and 4 new capabilities, and 19 systems, the alternatives were scaled down in 25% increments to 50% of the original scope, and up in 25% increments to 150% of the original scope. The formulas for the calculation of the elasticity of duration and labor are given by

$$\text{Elasticity of Duration} = \frac{Z \text{ (Defined as } \textit{\% Change in Duration})}{Y \textit{ (Defined as \% Change in Input)}} \tag{1}$$

$$\text{Elasticity of Labor} = \frac{Z \text{ (Defined as } \textit{\% Change in Labor})}{Y \textit{ (Defined as \% Change in Input)}} \tag{2}$$

After an alternative performance against the baseline C4I SoS was completed, the baseline performance was recorded. The C4I SoS was scaled down and up, and elasticity figures recorded at each 25% change in scope. *Elasticity of Duration* and *Elasticity of Labor* were calculated using the formula above, and the results for each change in SoS were recorded. Mean elasticity was calculated by adding the four elasticity figures and dividing the sum by four.

Table 9 shows the results of incremental and mean calculations for each alternative.

Alternative	Elasticity of Duration	Average Elasticity of Duration	Elasticity of Labor	Average Elasticity of Labor
Baseline (FEDOS)				
Baseline reduced by 50%	0.867		0.867	
Baseline reduced by 25%	0.867	**0.867**	0.867	**0.867**
Baseline increased by 25%	0.867		0.867	
Baseline increased by 50%	0.867		0.867	
MC3T				
MC3T reduced by 50%	0.782		0.782	
MC3T reduced by 25%	0.782	**0.782**	0.782	**0.782**
MC3T increased by 25%	0.782		0.782	
MC3T increased by 50%	0.782		0.782	
FCB				
FCB reduced by 50%	0.717		0.717	
FCB reduced by 25%	0.717	**0.717**	0.717	**0.717**
FCB increased by 25%	0.717		0.717	
FCB increased by 50%	0.717		0.717	
SCR				
SCR reduced by 50%	0.979		0.979	
SCR reduced by 25%	0.979	**0.979**	0.979	**0.979**
SCR increased by 25%	0.979		0.979	
SCR increased by 50%	0.979		0.979	
JTEM - CTM				
JTEM reduced by 50%	0.831		0.831	
JTEM reduced by 25%	0.831	**0.831**	1.661	**1.038**
JTEM increased by 25%	0.831		0.831	
JTEM increased by 50%	0.831		0.831	

Table 9. Elasticity Results for All Alternatives.

Elasticity calculations made from the output of the Arena Process Analyzer. Calculations for the individual elasticity associated with a change in the C4I SoS are displayed in the "Elasticity of Duration" column. Mean Elasticity is calculated by summing the four figures for the alternative and dividing by four. Within the limits of rounding, all alternatives displayed a consistent elasticity across the scale changes of the SoS. The only exception was the JTEM CTM alternative, which showed a significant elasticity when decreased to 75% of the original SoS, and otherwise exhibited the same elasticity (0.831) at all other ranges.

2. Power Simulation Results

POW-ER was used to generate the date for the "Days to Plan" EM. After simulating the performance of each alternative, the results of the simulations were calculated and expressed as a number of 8-hour days, using the organization and resources assigned to each alternative. Table 10 illustrates the calculated duration of the planning process for each alternative.

Alternative	POW-ER Estimation of Days to Plan a C4I Evaluation
Baseline (FEDOS)	140 Days
MC3T	121 Days
JTEM - CTM	127 Days
FCB	73 Days
SCR	158 Days

Table 10. POW-ER Simulation Results for JC3M Alternatives

This table provides the results of POW-ER Simulation and displayed the estimated total number of days each alternative requires to plan the C4I SoS evaluation. This data is a critical EM, and will serve as input to the AoA.

3. Results of Model Validation

The Labor Hours results from both the POW-ER and Arena models were validated against the FEDOS 2005 results. Table 11 below shows the Labor Hours reported from POW-ER and Arena as well as from the FEDOS empirical data. As shown in Table 11, the table shows that the Labor Hours reported by Arena was within 1.0 % when compared to the historical source data, and the hours reported by POW-ER were exactly the same as the FEDOS Labor Hours. The duration of the planning phase of the evaluation, as reported by Arena, was at 102% of the actual duration of the historical event, within the ±4% range set by the team. The duration as reported by POW-ER was 96.55% of the actual, and within the ±4% range set by the team. This provided the team with a high level of confidence that the models accurately represented the FEDOS 2005 processes, and that the models were realistic representations of those processes.

LABOR HOURS			RESULTS	
Alternative	**Known Input**	**Known Output (Labor Hours)**	**Arena Output (Labor Hours)**	**POW-ER Output (Labor Hours)**
Baseline (FEDOS)	19 Systems, 4 New Capabilities, 10 Old Capabilities	6,482	6,484 (Validated)	6,482 (Validated)
DURATION			**RESULTS**	
Alternative	**Known Input**	**Known Output (Duration)**	**Arena Output (Duration)**	**POW-ER Output (Duration)**
Baseline (FEDOS)	19 Systems, 4 New Capabilities, 10 Old Capabilities	145 Days	148 Days (Validated)	140 Days (Validated)

Table 11. Validation of Labor Hours.

POW-ER and Arena models were validated by ensuring the simulation results were within one percent of the known data from historical sources.

F. SUMMARY

M&S enabled the team to populate the JC3M Scoring Matrix with data from the simulation results. The matrix is the raw data that is needed for the AoA, which enables decision-makers to select the best alternative from a utility curve. Table 12 illustrates the results provided by M&S.

	Percentage of Traceable Measures	Days to Plan Evaluation	Quality of Planning Outputs	Elasticity of Labor	Elasticity of Duration
Alternatives	**1.3.2**	**1.4.3**	**1.4.3**	**4.1**	**4.1**
FEDOS		140 days		0.87	0.86
MC3T		121 days		0.78	0.78
JTEM CTM		73 days		1.04	0.83
FCB		158 days		0.97	0.97
SCR		127 days		0.71	0.71

Table 12. M&S Contribution to JC3M Scoring Matrix.

Evaluation Measures used for comparing alternatives generated by M&S include elasticity and duration. Labor hours (not shown) are used to calculate LCCE.

V. LIFE CYCLE COSTS

A. JC3M LIFE CYCLE COST OVERVIEW

1. Introduction

LCCE was a critical component of the System Engineering Design Process, because it allowed decision makers to quantify the costs of each alternative solution and compare them to other system engineering parameters such as: percentage of traceable measures, days to plan evaluation, quality of planning outputs, and elasticity of labor and duration. Decision makers could then assess the risks and benefits of implementing each of the JC3M alternatives. This chapter will explain the cost estimation methods considered, the estimation approach used, how cost data was collected, and provide an analysis of the results.

The LCCE provided an estimate of the total life cycle cost for each of the five alternative JC3M solutions over a ten year period. JC3M could be implemented and used for more than ten years, or be replaced sooner. The team expected a new C4I SoS evaluation system to be developed in order to provide additional evaluation capability in response to changing conditions, technology, and doctrine, and chose ten years as a representative duration for JC3M.

The LCCE was limited to estimating the costs of planning a C4I SoS evaluation. The design of JC3M assumed the use of existing processes for both the conduct and reporting of C4I SoS evaluations; test organizations implementing the JC3M system were not expected to see cost changes for these processes. The cost of buildings, C4I hardware and software, and supporting infrastructure required to conduct C4I SoS evaluations were not considered in the LCCE. These items were considered to be essential resources for any organization already conducting C4I SoS evaluations, and were considered sunk costs, i.e. a cost incurred in the past that will not be affected by current or future decisions [OMB Circular A-94, 1992]. Sunk costs were not considered in the LCCE or comparison of alternatives [Thuesen and Fabrycky, 2001: 24].

The life cycle phases of the JC3M system, used in the LCCE, were Development and Implementation, Operations and Support, and Transition and Disposal.

The development phase included interaction with stakeholders to begin the requirements process, designing the functional architecture, modeling, trade studies, and analysis of alternatives [Buede, 2000]. Implementation was the phase in which the alternative solution was tailored for use under local operating conditions. Operations and Support (O&S) was the phase in which operations, maintenance, and support of the JC3M systems and associated support equipment took place. Transition and Disposal was the phase in which JC3M would be retired.

In generating the LCCE, a mix of personnel, infrastructure, and facilities was stipulated. The resource pool identified to conduct JC3M alternatives consisted of seven Senior System Analysts who identified system capabilities and defined and documented test cases; six Senior Tech Specialists who planned, designed, coordinated, and controlled the evaluation; and one Senior Program Manager who managed and coordinated the project and program activity. Physical facilities included laboratory spaces, network connectivity and infrastructure, and adequate communications. An organization with a significantly different resource pool or physical plant will experience different O&S costs than what was estimated in this project.

a. Development and Implementation Phase

The Development and Implementation phase included the design, development, and procurement of systems and support items necessary to conduct planning of C4I SoS evaluations. In estimating the cost of implementation for the alternatives, published cost estimation information and interviews with SME were used to obtain the necessary information. Interviews were performed with MCTSSA Resource Manager [Manning (c), 2007], Architecture Branch Head [Nguyen, 2007], Data Analysis Lab Manger [Chance, 2007], FEDOS SME [Hoesly, 2007], MC3T IPT Lead [McLean (b), 2007] and Technical Lead [Finn, 2007]. These interviews along with Technical Support Plans [Manning (b), 2005] and Consolidated Requirement Assessment [McLean (a), 2007] were the source of the baseline and MC3T cost estimates. Based on SME interviews, historical financial data from the 2005 FEDOS test event, and monitoring the progress of MC3T at MCTSSA, the team determined that the development and implementation phase of the JC3M system would last approximately one year.

b. Operation and Support Phase

The Operation and Support (O&S) phase included operation, maintenance, and support of the systems and associated support equipment over the life of the system. As noted, the LCCE only included the costs of planning a C4I SoS evaluation. The O&S phase was determined to have a duration of nine years from the year of implementation. The team expected that by the end of the ninth year the JC3M system would be replaced as legacy systems are retired and new systems are designed and developed as part of the SoS. As the JCIDS process continues to develop, more systems should be "born joint" and their capabilities, as part of the C4I SoS, should be understood. JC3M will need to be continually evaluated and updated to accommodate changes in technology, system and SoS operations, and concepts of employment.

c. Transition and Retirement Phase

The Transition and Retirement phase included costs associated with the termination and retirement of the process**.** If the O&S phase was extended beyond, or reduced from, nine years this phase would take place later or earlier, but was still projected to last approximately one year. The team estimated that the cost of this phase would be minimal due to the conceptual nature of the activities conducted by the JC3M system. The three phases of the LCCE are graphically displayed in Figure 33.

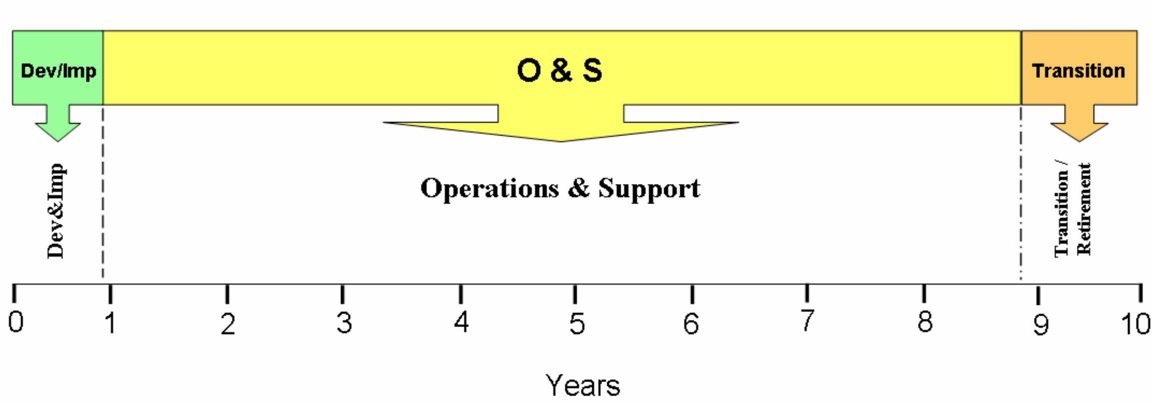


Figure 33. Phases of JC3M Life Cycle.

The three life cycle phases of the JC3M alternatives under consideration are Development and Implementation, Operations and Support, and Transition and Retirement. This graphically displays the phases over the ten year life cycle.

2. Life Cycle Cost Elements

a. Development and Implementation Costs

The development and implementation cost for JC3M was treated as a non-recurring cost. The targeted customers of the JC3M system were assumed to be DoD organizations involved with C4I SoS test and evaluation. The cost for developing and implementing JC3M came primarily from process documentation and initial training. Because of the conceptual nature of JC3M, there were no costs expected from the procurement of software packages, software licenses, or hardware additions or upgrades.

b. Operation and Support Costs

O&S cost is the major portion of the life cycle cost of JC3M. The O&S Cost-Estimating Guide [Cost Analysis Improvement Group, 2002] defines O&S cost as the "costs of personnel,… services, and sustaining support…." associated with any system. To arrive at a realistic estimate of JC3M over its life cycle, current information was gathered from a variety of interviews (see Section A.1.a "Development and Implementation") and financial data from the FEDOS TSP [Manning (b), 2005] and MC3T CRA [McLean (a), 2007], internal MCTSSA documents used to forecast and manage the respective projects. The O&S cost elements included the labor cost of personnel required to plan a C4I SoS evaluation; follow on training; and the software and hardware periodic upgrades, license renewals, and maintenance contracts required for planning C4I SoS evaluation.

c. Transition and Retirement Costs

The transition and disposal cost of the JC3M system consisted of the manpower costs of personnel required to provide customer support during the transition period, document archiving, and configuration management. Customer support was estimated to require the services of at least one engineer to work with users to facilitate the teardown and disposal of systems and at least one configuration management specialist to assist in archiving relevant documents and software. This phase was estimated to last no more than one year after the end of the O&S phase of the JC3M life cycle. The majority of JC3M documents would be electronically stored and managed; therefore, costs in this phase are associated with computers and online storage space. The cost to transition and retire the planning processes associated with JC3M are considered to be minimal due to the conceptual nature of JC3M.

3. Cost Estimation Assumptions and Constraints

The cost estimate assumptions and constraints are summarized as follows:

- The application of JC3M processes did not require any additional equipment or tools.
- JC3M planning processes are conceptual and no specialized software or hardware was required.
- Specialized education or training was not required in applying the JC3M process.
- The cost for developing and implementing JC3M was a one-time non-recurring cost.
- The cost for the disposal phase was minimal due to the conceptual nature of JC3M.
- Overhead cost in each organization was not considered.
- The team recognized the variance in duration of "Days to Plan" among the alternatives, but for consistency, elected to consider each alternative conducting one C4I SoS evaluation per year.

B. COST ESTIMATION METHODS CONSIDERED

The JC3M LCCE was completed using a combination of the Analogy cost method [Defense Acquisition Guidebook, 2006] and the Activities-Based Costing (ABC) method [Blanchard and Fabrycky, 1998: 580]. These methods are described below.

Estimation by Analogy is employed when the project under consideration is similar to a previously fielded or implemented system. Estimation by analogy requires that current systems similar in design and function are selected for the basis of cost estimation [Defense Acquisition Guidebook, 2006].

MC3T is a system designed for defining, documenting, and evaluating the performance of a MAGTF C4I SoS as a single system, in accordance with modern systems engineering practices. Because JC3M was designed to perform functions similar to those of MC3T, the team determined that analogy was an appropriate method of cost estimation. Historical cost data from the MC3T system was used to estimate the cost of development and implementation of MC3T. MC3T cost data was obtained primarily from interviews with the MC3T IPT Lead McLean (a) [2007], and the draft CRA [McLean (b), 2007].

ABC is used when estimating the cost to carry out the activities and processes of a system. The main goal of this methodology is to ensure that all costs are traceable back to the functions or processes that actually occurred within the system. In the ABC methodology, costs are directly traceable to the applicable cost-generating process and product. Cost can be easily estimated on a functional basis, and the emphasis is on resource consumption. Processes and products are performed by activities, and activities consume resources. The ABC approach fosters the establishment of cause-and-effect relationships, enables the identification of the high-cost contributors, and eliminates double counting that is typically inherent with the application of direct and indirect costs. [Blanchard and Fabrycky, 1998: 580-581]. The ABC method was used to estimate O&S cost for the JC3M alternatives.

The JC3M system utilized resources to execute functions and within these functions processes and tasks were executed in order to produce the desired outputs. The cost of each process or task, in labor-hours consumed, was directly traceable back to the cost-generating function. The input to the cost model was based on the labor hours required to execute the functions associated with each of the alternatives.

The team also considered the Engineering Estimate method and the Actual Cost method [Defense Acquisition Guidebook, 2006]. The engineering estimation method is employed when the system is broken down into components. However, since the JC3M system consists primarily of activities, this methodology was not suitable. The Actual Cost Estimation method was considered but because there was no actual cost experience or trends from prototypes, engineering development models, or early production items to project estimates of future costs this method was also rejected.

C. JC3M COST ESTIMATION APPROACH

The team followed the cost estimation approach described by Blanchard and Fabrycky [1998: 567] to estimate the costs for the JC3M system. The approach was tailored to fit the requirements of the JC3M system as defined in Chapter II "Problem Refinement."

The cost model was designed to estimate the life cycle cost of planning C4I SoS evaluations as conducted by each of the alternative solutions. The cost model was constructed using Microsoft Excel® spreadsheet software. The cost model calculated the cost of each task, year, life cycle phase, and overall cost for each alternative, and the costs for each alternative were summarized.

In each phase of the JC3M life cycle, tasks and sub-tasks were executed in order to support the functions of the system. These tasks and sub-tasks were identified based on the functional decomposition of the system. The output values from the LCCE provided the cost inputs to the AoA.

The JC3M Cost Breakdown Structure (CBS) used a hierarchical framework for estimating the life cycle cost. The CBS provided a structure that identified the elements or categories of costs that were incurred in each phase of the JC3M life cycle. It also served as a guide for cost data collection for each of the high level functions of the JC3M system. Because each of the alternatives was unique, not all the alternatives had cost data for the identified cost categories. The FEDOS alternative did not define performance measures, and did not report a cost for this task.

The CBS defined the specific elements included in the cost estimate and organized the LCCE results in a hierarchy [Defense Acquisition Guidebook, 2006]. The CBS identified the cost elements for each phase and guided cost data collection for each of the high level functions of JC3M. Figure 34 is a graphical representation of the JC3M CBS.

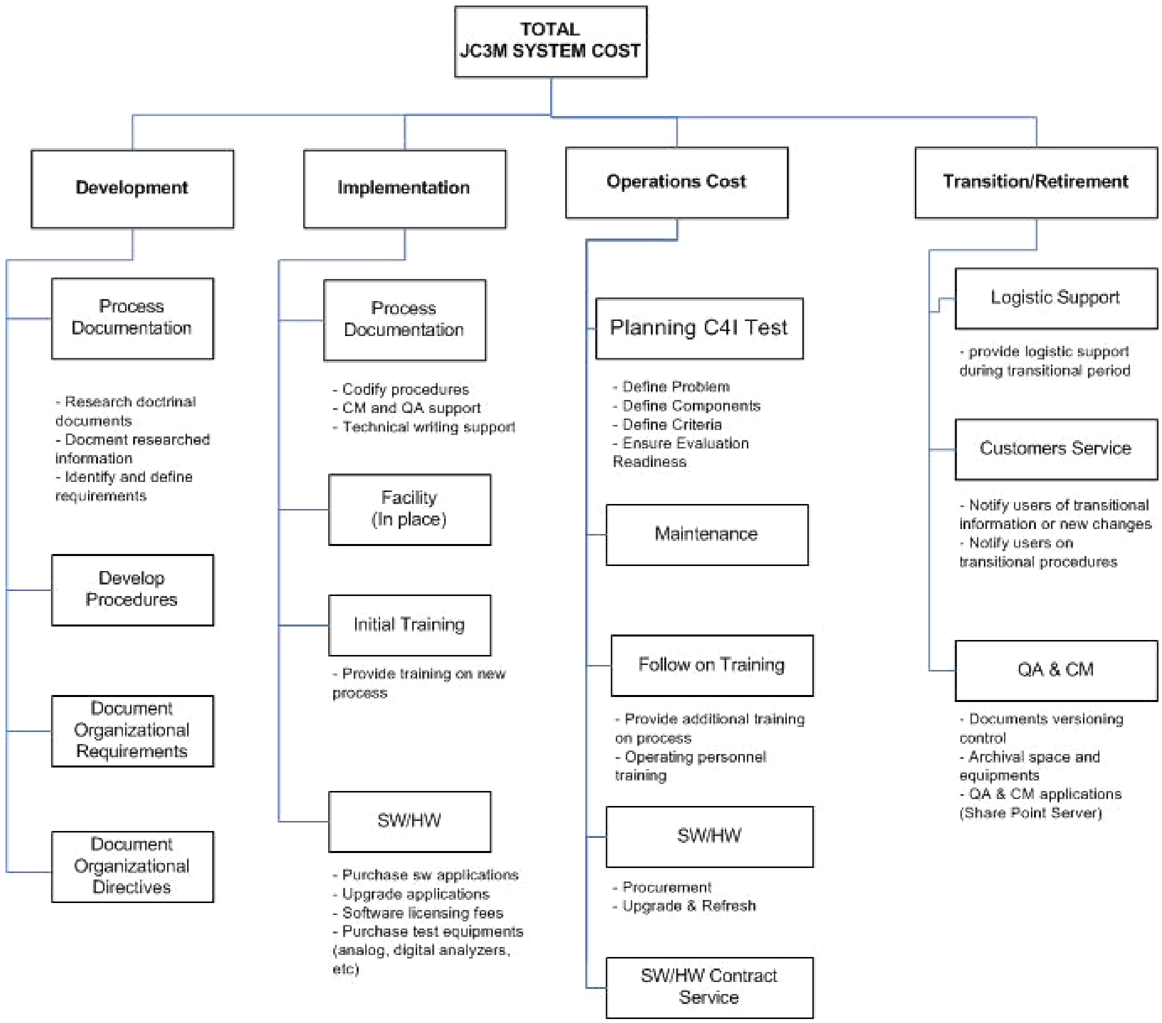


Figure 34. Cost Breakdown Structure of JC3M.

The CBS provided a structure that identified the categories of costs in each phase of the JC3M life cycle. It also served as a guide line for cost data collection for each of the high level functions of the JC3M system.

D. COST DATA COLLECTION

Data for this effort was extracted from the MCTSSA CRA [McLean (a), 2007] that provided resource requirement assessments for funding, staffing, data collection and monitoring networks, data capture, and information assurance. The O&S cost of JC3M was most influenced by the direct labor costs of the technical staff.

The MCTSSA test team consisted of federal civilian employees, contractors, and a small military staff that provided C4I systems support, operation, and management. Fully burdened labor rates for civilians and contractors were provided by the MCTSSA comptroller office for Fiscal Year (FY) 2007 [George (a), 2007]. Fully burdened FY

2007 labor rates [Military Composite Pay and Reimbursements Rate Table, 2007] were used to calculate cost of military personnel.

The MC3T IPT lead [McLean(b), 2007] was interviewed to obtain information on the duration of the development, implementation, and operations of MC3T. Projected personnel labor hours, software and hardware cost, as well as the number of billets required were obtained from the draft version of the CRA provided by the MC3T IPT Lead [McLean (a), 2007]. The CRA was the primary source of data for the cost estimation. The team also interviewed stakeholders and subject matters experts to obtain cost data and information that was not readily available. In calculating the personnel labor costs, the fully burdened rate for government civilians [DoD Civilian Personnel Management Service, 2007], military [Office of the Under Secretary of Defense for Personnel and Readiness, 2007], and contractor billets [GSA schedule for Systems Engineering Support Service] were used. Interviews with the MCTSSA assistant comptroller [George (b), 2007] were also conducted to provide additional information on the fully burdened labor rates for civilians and contractors at MCTSSA.

E. ANALYSIS OF COST DATA

1. Development Costs

Development costs for the FEDOS alternative were recorded as $0 in the LCCE, because this alternative was fully developed. Development costs for the MC3T alternative were recorded as $0 in the LCCE, because this alternative was considered fully developed. Resources used for development of the MC3T alternative were identified, based on review of historical data and SME interviews, and used by analogy to estimate the development costs of both the FCB and SCR alternatives which did not have historical development costs. FCB and SCR estimated developments costs are adjusted to account for specific differences between the alternatives. Development costs for the JTEM CTM alternative were based on SME interviews, and are described below. All development costs are recorded in the LCCE and summarized in Table 13.

Development of MC3T included a Self Assessment Team (SAT), a multidisciplinary IPT formed to evaluate MC3T processes and assist in refining processes prior to execution. The SAT also served to capture lessons learned and document changes for process improvement. The estimation of the labor cost for the SAT was based on the MC3T POAM-001-V1 [McLean (c), 2007], the Requirements for Members of the MCTSSA Self Assessment Team, [Villar (a), 2007] and an interview with the SAT lead [Villar (b), 2007].

Colonel Eileen Bjorkman, United States Air Force (USAF), Test Director, Joint Test Evaluation Methodology, stated the JTEM CTM will not be fully developed until FY09, and estimated the total remaining cost to develop the CTM through 2009 at $3.5M [Bjorkman, (b) 2007]. This estimate includes JTEM CTM Community of Interest work, documentation and process writing, and participation in events. The JTEM CTM development cost does not consider overhead cost such as utilities, facilities operation and maintenance, administration costs, and other overhead cost not directly related to labor cost. This estimation is consistent with the cost estimations used for development of the other alternatives. This development cost is allocated in the cost model as $1.03M for the remainder of year 1 (FY07), and $2.47M for year 2 (FY08).

2. Implementation Costs

Implementation costs for the FEDOS alternative were not found in historical data. Implementation costs for the FCB, SCR, and JTEM CTM alternatives were not available because they have not been used. The cost to implement these four alternatives was estimated by analogy with the MC3T implementation costs, because historical data is available, the alternatives perform similar tasks, and are of similar complexity. All implementation costs are recorded in the LCCE and summarized in Table 13.

The CRA [McLean (a), 2007] provided the most accurate source of data on personnel, data capture, hardware, and software costs of MC3T implementation. This estimate includes costs of training personnel, documentation, capturing lessons learned, documenting changes, and software licensing fees, and totals approximately $1.1M. The implementation effort will take MC3T to the start of the first evaluation; the conduct of the initial C4I SoS evaluation is not included.

Implementation of the JTEM CTM does not begin until year 3 of the LCCE, when development of the alternative is completed.

3. Results of Cost Data Analysis

The JC3M team determined the most expensive alternative was the FCB alternative, at a cost of \$8.13M over the ten-year projected lifecycle. The team also noted that FCB is approximately \$0.41M more than SCR. The team calculated the cost of FCB as a cost to DoD, i.e. while the senior SMEs who generate the performance measures do not charge their efforts directly to a C4I test organizations, their time and effort is a cost to DoD. In order of increasing cost, the other alternatives were FEDOS at \$5.01M; MC3T at \$5.97M; JTEM CTM at \$6.97M; and SCR at \$7.72M.

The team determined that MC3T was estimated to cost approximately \$0.96M more than FEDOS, which it has replaced. While this is a significant cost difference, the increase can be directly attributed to the increased in scope, duration, and level of effort involved in MC3T, which, in addition to the factual data cited above, anecdotally supported the increased cost of MC3T.

The team noted the alternative with the lowest estimated O&S cost was the JTEM CTM alternative, at \$2.3M, followed by FEDOS at \$3.9M, MC3T at \$4.8M, SCR at \$5.6M, and FCB at \$5.8M. This is significant because O&S represents the largest portion of the LCCE, and is the portion directly assumed by a test organization that implements any alternative.

Implementation of JC3M would modify topics assessed in a C4I SoS evaluation, which could cause cost changes in the conduct and reporting phases of the evaluation. In part to assess these potential changes, the team recommended validation of JC3M results (see Chapter 7, Section D “Conclusion”) through a “real world” evaluation.

The team noted that due to the continuing development of the JTEM CTM alternative, the O&S phase would not start until one year after the other four alternatives. As a result, over the ten year duration of the LCCE, the JTEM CTM would complete one less C4I SoS evaluation. Table 13 summarizes the LCC results.

Alternatives	Life-Cycle Year 1	2	3	4…9	10	Total Cost ($)
FEDOS						
Development	0	0	0	0	0	0
Implementation	1,052,527	0	0	0	0	1,052,527
Operational & Support.	0	419,497	419,497	419,497	2,200	3,908,178
Transition and Disposal	0	0	0	0	50,000	50,000
Total Cost	1,052,527	419,497	419,497	419,497	52,200	**5,010,706**
MC3T						
Development	0	0	0	0	0	0
Implementation	1,169,414	0	0	0	0	1,169,414
Operational & Support.	0	525,537	525,537	525,537	2,200	4,756,500
Transition and Disposal	0	0	0	0	50,000	50,000
Total Cost	1,169,414	525,537	525,537	525,537	52,200	**5,975,913**
JTEM CTM						
Development	1,030,000	2,470,000	0	0	0	3,500,000
Implementation	0	0	1,169,414	0	0	1,169,414
Operational & Support.	0	0	0	558,535	2,200	2,253,410
Transition and Disposal	0	0	0	0	50,000	50,000
Total Cost	1,030,000	2,470,000	1,169,414	558,535	52,200	**6,972,824**
FCB						
Development	1,021,835	0	0	0	0	1,021,835
Implementation	1,301,282	0	0	0	0	1,301,282
Operational & Support	0	650,223	650,223	650,223	2,200	5,753,985
Transition and Disposal	0	0	0	0	50,000	50,000
Total Cost	2,323,117	650,223	650,223	650,223	52,200	**8,127,101**
SCR						
Development	952,007	0	0	0	0	952,007
Implementation	1,169,414	0	0	0	0	1,169,414
Operational & Support.	0	624,451	624,451	624,451	2,200	5,547,811
Transition and Disposal	0	0	0	0	50,000	50,000
Total Cost	2,121,421	624,451	624,451	624,451	52,200	**7,719,232**

Table 13. Life Cycle Cost Summary.

Summary sheet of life cycle costs for all alternatives based on CBS over a 10-year life cycle

VI. ANALYSIS OF ALTERNATIVES

A. METHODOLOGY

The team conducted an Analysis of Alternatives in order to compare the performance of each of the five alternatives described in Chapter III, Design Alternatives. AoA compared the outputs of EMs and LCCE for each alternative. The team utilized an approach that provided a comparison of total cost to total performance.

> An Analysis of Alternatives (AoA) compares alternatives by estimating their ability to satisfy the identified requirements through an effectiveness analysis and by estimating their life cycle costs (LCC) through cost analysis. The results of these two analyses are used together to produce a cost-effectiveness comparison that allows decision makers to [evaluate] cost and effectiveness simultaneously [Feuchter, 2004: 7].

B. MULTI-ATTRIBUTE UTILITY THEORY

Multi-attribute Utility Theory (MAUT) is a "quantitative method for aggregating a stakeholder's preferences over conflicting objectives to find the alternative with the highest value when all objectives are considered" [Buede, 2000: 361]. The five alternatives under consideration were evaluated and compared against each other in this section using MAUT. The goal of the analysis was to provide a structured method in the decision-making process. There are several techniques that can be used to compare alternatives when there are multiple evaluation measures with different units of measure. The team decided to use the Value Modeling technique as part of the JC3M SEDP.

Sage and Rouse [1999: 1128] stated that to select the preferred alternative it is necessary to combine evaluation measures into a single measure of the overall desirability of an alternative. This is done by developing a *value function* ($v(x_1, x_2, \ldots, x_n)$). The equation for the value function, under the condition of linear additive independence of attributes, is given by

$$v(x_1, x_2, \ldots, x_n) = w_1 v_1(x_1) + w_2 v_2(x_2) + \cdots + w_n v_n(x_n) \tag{3}$$

where $x_1, x_2, \ldots x_n$ are the EMs for an objective/requirement, $v_1(x_1), v_2(x_2), \ldots v_n(x_n)$ are the utility scores of the EMs for a specific alternative, and $w_1, w_2, \ldots w_n$ are the weights for each EM.

C. VALUE MODELING TECHNIQUE

Value modeling as applied to this project was discussed in detail in Chapter II, Problem Refinement. Value modeling has three steps, 1) the definition of a Qualitative Value Model, 2) the definition of a Quantitative Value Model, and 3) the definition of an Additive Value Model. Figure 35 provides an overview of the structure of value modeling.

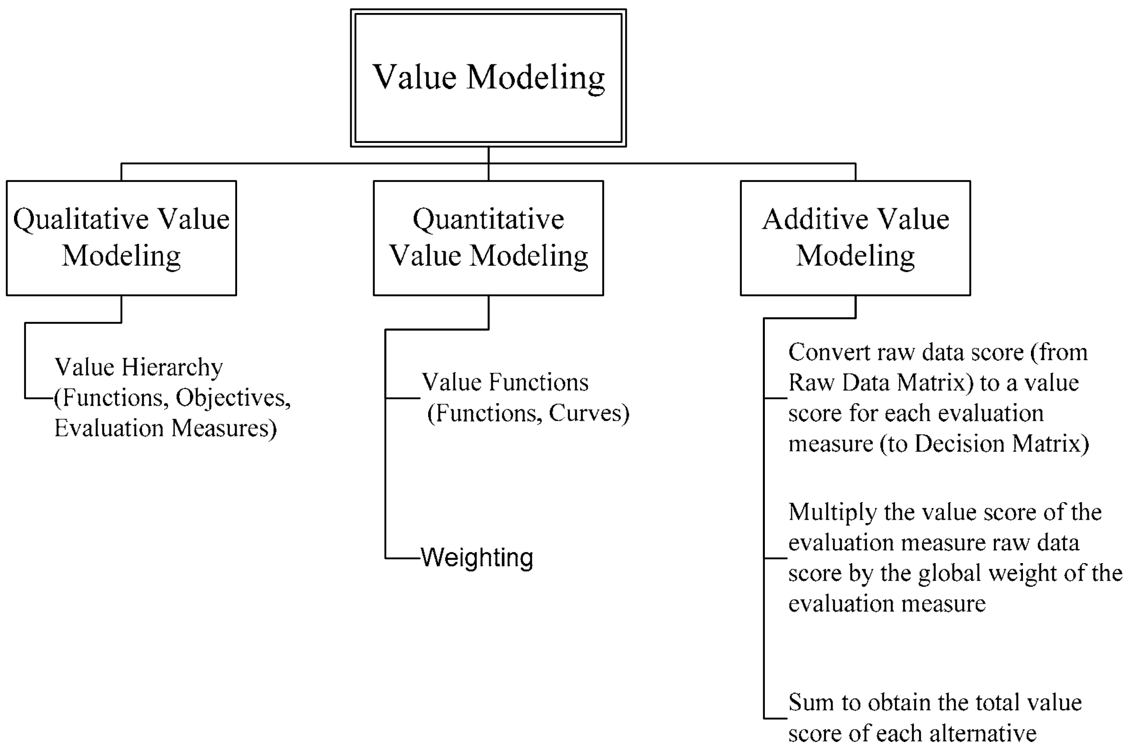


Figure 35. High Level Outline of Value Modeling.

Value Modeling is composed of Qualitative Value Modeling, Quantitative Value Modeling, and Additive Value Modeling. Details of the JC3M Qualitative Value Modeling process are provided in the Chapter II "Problem Refinement." Quantitative Value Modeling includes the definition of relative importance of EM; Additive Value modeling converts raw scores to total value of each alternative.

The Critical EMs used to compare performance of each alternative were described in Table 1, Chapter II, Problem Refinement. The EMs used in the functional analysis were the same EMs used to evaluate the alternatives. This provided clear traceability between the functional requirements and the AoA. In order to perform an effective evaluation of performance it was necessary to have a consistent and accurate set of criteria. These criteria must be based on the design objectives, i.e., what it is that the design is meant to achieve [Cross, 2000: 140]. The criteria used to evaluate EMs for the alternatives are shown in Table 14. Table 14 expands on Table 1 by adding the ideal values of the EMs.

	Percentage of Traceable Measures	**Days to Plan Evaluation**	**Quality of Planning Outputs**	**Elasticity of Labor**	**Elasticity of Duration**
JC3M Function	Define Measures 1.3.2	Planning Results 1.4.3	Planning Results 1.4.3	Input System Flexibility 4.1	Input System Flexibility 4.1
Definition	Alternative generated measures, traceable to stakeholder requirements, divided by the number of measures generated by the alternative.	Sum of labor hours required, expressed in days, to plan C4I SoS evaluation	Assign an overall quality level to the planning documents produced.	Divide percent change in labor hours to conduct planning phase of JC3M by the percent change in systems under test.	Divide percent change in duration to conduct planning phase of JC3M by the percent change in systems under test.
Range	0 – 100%	≥ 0	Likert Scale of 1 - 4	$0 - \infty$	$0 - \infty$
Ideal Value	100%	Less is better	4 is best	Less is better	Less is better

Table 14. JC3M Critical Evaluation Measures.

Critical EMs used to compare the performance of alternative solutions. This table expands on Table 1 by including ideal values.

D. QUANTITATIVE VALUE MODEL

The Quantitative Value Model utilized the decision maker's preferences with respect to EMs. This involved defining utility curves and weights for each EM. Utility curves were used to normalize EM scores, i.e., convert a raw score received from M&S or from an SME, into a utility score. For example, consider the top speed of a vehicle as an EM of interest to a decision maker. If a vehicle being considered for purchase had a top speed of 60 mph, this raw value would be converted to a value on a scale of 0 to 1, where 0 represents no utility to the stakeholder, and 1 represents the highest utility to the stakeholder. The "worth" of the top speed of 60 mph would be dependent on the decision maker's preferences and could be modeled with a utility function. The utility score of EMs were expressed on a common scale in order to allow useful comparisons.

There may be multiple EMs and each may have different relative worth to a decision maker. In the example above, purchase price may be more important to a decision maker than top speed, braking distance, or acceleration. Based on the preferences of the decision maker(s), appropriate weights were assigned to each EM in order to reflect their relative importance.

1. Eliciting Utility Curves from Stakeholders

The team evaluated two methods to implement utility functions, also referred to as Standard Scoring Functions (SSFs). [Wymore, 1993] developed a set of twelve SSFs. In addition, [Buede, 2000:365] described a family of exponential utility functions. [Daniels, 2001:209] compared both methods and concluded that only eight utility functions are required for all applications that he and his team had encountered. Four of the eight are Wymorian SSFs. The team selected two Wymorian functions: SSF 3 and SSF 9, because they fit the parameters that can be assignable to the evaluation measures being modeled by the team [Daniels, 2001:206].

The SSF3 guideline is: "If more is better, the customer can provide both a finite upper bound and a finite lower bound, then choose SSF3. This is by far the most common scoring function used when dealing with an EM where more is better" [Daniels, 2001: 204].

The SSF9 guideline is: "If more is worse, and the stakeholder can provide both a finite upper bound and a finite lower bound, then choose SSF9. This scoring function is by far the most frequently used with EMs where more is worse" [Daniels, 2001: 207].

The five parameters required to create Wymorian SSFs are defined as follows:

L - The lower threshold of performance for the EM below which the value to the customer is undesirable (but not necessarily unacceptable) and is assigned a zero score.

B - The parameter B is called the baseline value for the EM and can be chosen as the design goal or the status quo for this or similar systems. By definition, baseline values are always assigned a score of 0.5.

U - The upper threshold of performance for the EM above which the value to the customer is assigned a score of one.

S - The parameter S determines the behavior of the scoring function in the neighborhood of the baseline value B. Mathematically, S is the slope of the tangent to the scoring function at the baseline value B. The slope represents the maximum incremental change in the customer's quantitative judgment with each incremental change in input.

D - The parameter D represents the domain of definition of the scoring function. D is defined as the range between L and U. Conceptually, D clearly states the range of input values that are possible from a build-ability viewpoint or legal due to mandatory requirements. Values outside this range constitute impossible or unacceptable inputs [Daniels, 2001: 203].

Each SSF figure included the SSF Value or Utility Score along the y axis and the raw EM score along the x axis. In addition, each figure included the parameters that can be used to recreate the SSF. Figure 36 illustrates Wymore's SSF 3 and SSF 9.

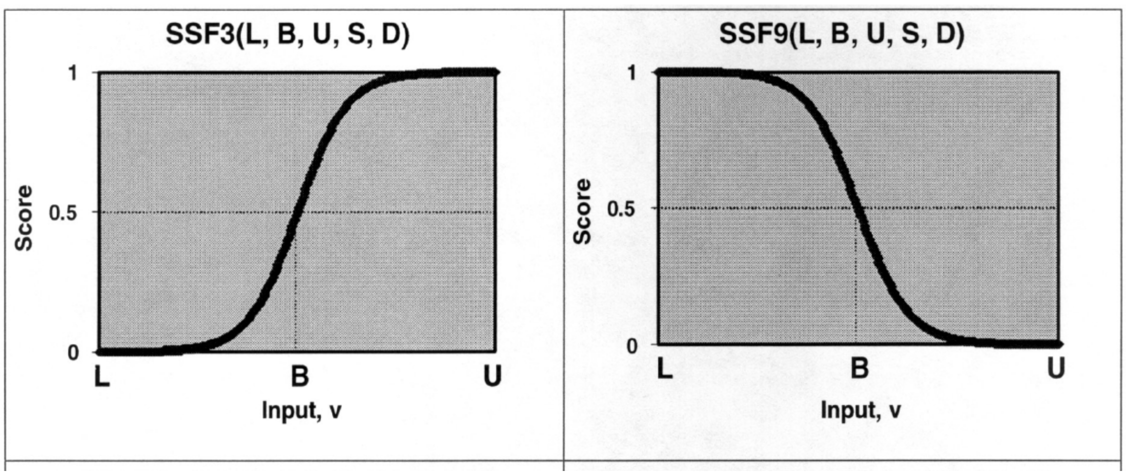


Figure 36. Wymorian Standard Scoring Functions 3 and 9.

SSF 3 and SSF 9 were chosen by the team to use during AoA. Five parameters were needed to create a Wymorian SSF. These are Lower Limit (L), Baseline Value (B), Upper Limit (U), Slope (S), and Domain (D). SSF 3 was used to score measures that are more valuable as they increase (Percentage of Traceable Measures). SSF 9 was used to score measures that are more valuable as they decrease (Days to Plan Evaluation).

Thomas Lee Rodgers in cooperation with A. Terry Bahill from the University of Arizona developed a software program that implements the SSFs described here [Rodgers and Bahill, 2007]. The team used this software to implement the SSFs described in Figures 38 through 41.

The team constructed initial SSFs for the five EMs and presented them to a group of SMEs, as described in Appendix C. Representatives from JTEM, JITC, NPS, MCTSSA, and NAWC China Lake were invited to provide stakeholder preferences for the Quantitative Value Model. Two representatives from MCTSSA, with United States Marine Corps (USMC) C4I SoS test experience, and two representatives from NAWC China Lake, with United States Navy (USN) C4I SoS test experience, were available and consulted to provide stakeholder preferences. Stakeholders approved the SSFs and provided weights for each EM using the Analytical Hierarchy Process (AHP).

2. Percent Traceable Measures Utility Curve

Percentage of Traceable Measures was an EM that reported on how well the alternative creates performance measures traceable to authoritative sources. As the percentage increased, the performance measures were more valuable to the organization conducting the C4I SoS evaluation. The SSF used to score this EM is illustrated in Figure 37.

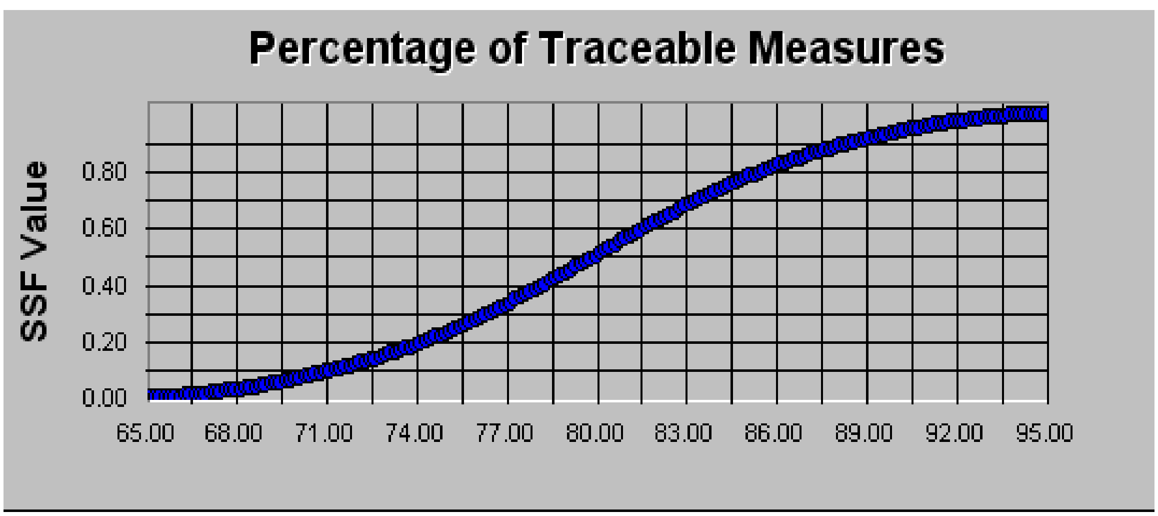


Figure 37. Utility Function for Percentage of Traceable Measures.

This is the stakeholder validated Utility Function used for this EM. A higher percentage was more desirable. Values less than 65% received a utility of 0. Values greater than or equal to 95% received a utility of 1.0. SSF 3 Parameters were L = 65%, B = 80%, U = 95%, D (U – L) = 30%, and S = 0.67.

3. Days to Plan Utility Curve

The Days to PlanEM reported how many work days were required by the alternative to plan the evaluation of the baseline C4I SoS. As the number of days decreased, the alternative became more valuable to the organization conducting the C4I SoS evaluation, because more evaluations could be planned over the same time period, or plans could be performed more quickly. The SSF used to score this EM is illustrated in Figure 38.

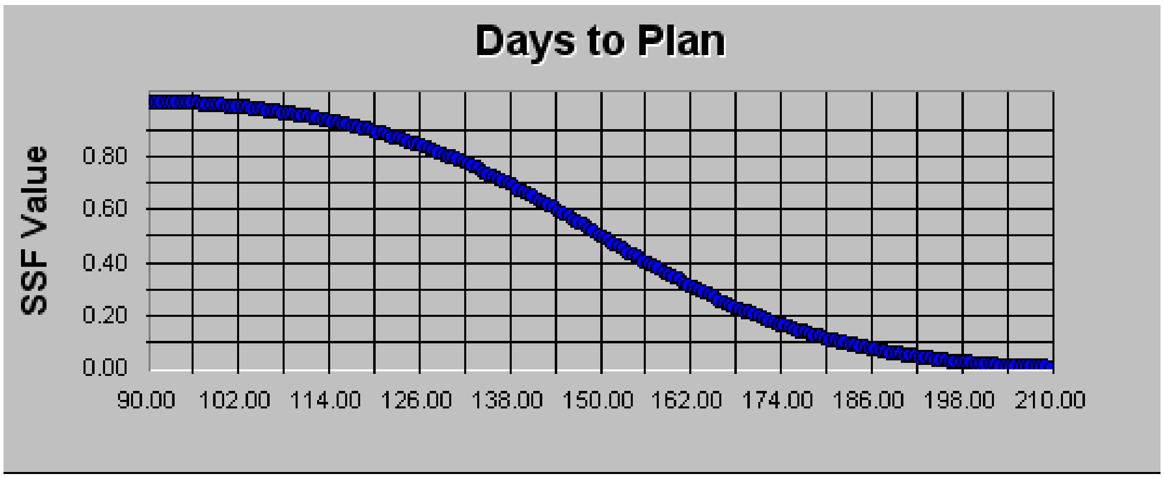


Figure 38. Utility Function for Days to Plan Evaluation.

This is the stakeholder validated Utility Function used for this EM. A lower number of days was more desirable. Values less than 90 days received a utility of 1.0. Values greater than or equal to 210 days received a utility of 0. SSF 9 Parameters were L = 90 days, B = 150 days, U = 210 days, D (U – L) = 120, and S = - 0.0167.

4. Quality of Planning Outputs Utility Curve

Quality of Planning Outputs was an EM that reported on overall “goodness” of the test plans and test procedures produced by the alternative. As quality increased, the alternative became more valuable to the organization conducting the C4I SoS evaluation, because evaluations become more accurate, more effective, and more efficient. The SSF used to score this EM is illustrated in Figure 39.

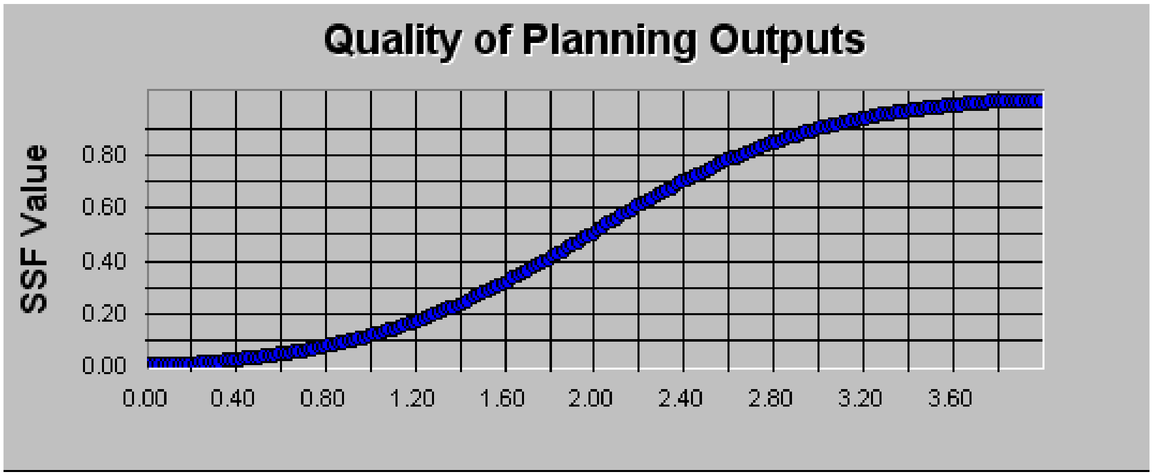


Figure 39. Utility Function for Quality of Planning Outputs.

This is the stakeholder validated Utility Function used for this EM. A raw score of 4.0 is ideal and received a utility of 1.0. SSF 3 Parameters were L = 0, B = 2.0, U = 4.0, D (U – L) = 4.0, and S = 0.5.

5. Elasticity of Labor and Elasticity of Duration Utility Curves

Elasticity of Labor was an EM that reported on how the alternative responded to changes in the C4I SoS under evaluation. Specifically, the percent change in labor hours to conduct planning phase of JC3M was divided by the percent change in input parameters (number of SUT, number of new capabilities, number of old capabilities) and the resulting ratio was the measure of elasticity.

Values less than 1.0 are inelastic, and indicated that changes in the C4I SoS under evaluation cause a change in the number of labor hours required at a smaller rate. As the SoS increased in size, there was less labor required, per system, to evaluate the performance of the SoS. Elasticity is valuable when conducting evaluations of C4I SoS as large or larger than the candidate test architecture described in Chapter IV section C.2, Select a Candidate C4I Test Architecture. The SSF used to score Elasticity of Labor is illustrated in Figure 40.

Elasticity of Duration, also illustrated in Figure 40 is an equivalent EM, and measured how the duration (number of days) of the alternative process changed in response to changes in the C4I SoS under evaluation. Elasticity of Duration would be valuable when conducting evaluations of C4I SoS as large or larger than the candidate test architecture described in Chapter IV section C.2, Select a Candidate C4I Test Architecture.

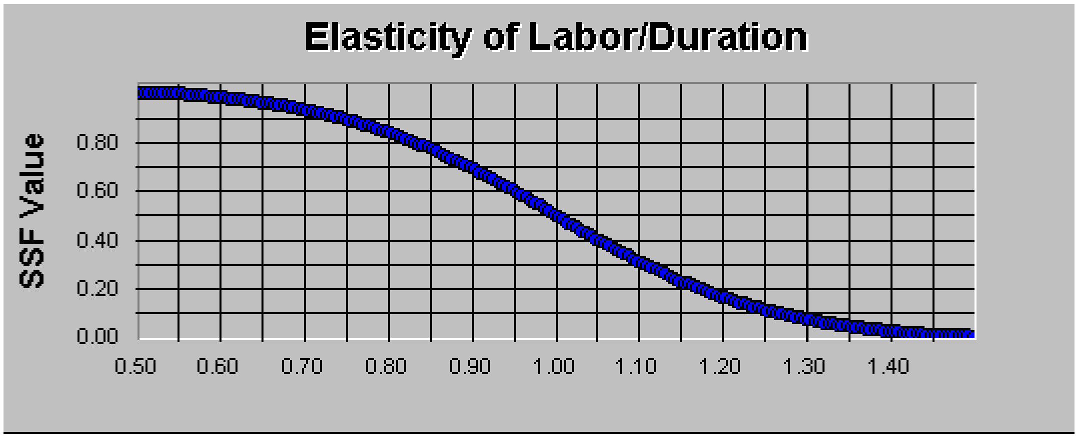


Figure 40. Utility Function for Elasticity of Labor and Elasticity of Duration.

This is the stakeholder validated Utility Function used for this EM. A lower number for Elasticity was desirable. Values less than 0.5 days received a utility of 1.0. Values greater than or equal to 1.5 days receive a utility of 1.0. SSF 3 Parameters were L = 0.5, B = 1.0, U = 1.5, D (U – L) = 1.0, and S = 2.0.

Values less than 1.0 are inelastic, and indicated that changes in the C4I SoS under evaluation cause a change in the number of days required at a smaller rate. As the SoS increased in size, there were less days required, per system, to conduct planning of the SoS test. Elasticity is valuable when conducting evaluations of C4I SoS, to determine the effects that increases in the number of systems will have on the duration for planning the SoS evaluation. Chapter IV section C.2, described the baseline candidate C4I test architecture; by adding or reducing the number of systems one can determine the elasticity of the number of days required to plan a C4I SoS event.

E. ANALYTICAL HIERARCHY PROCESS

Buede [2000: 369] described several methods to elicit weights for calculating the relative worth of EM. The team chose the AHP because it is useful for cases where there are 3-7 objectives [Saaty, 1994].

The weights were elicited from three SMEs, using the AHP verbal mode for pairwise comparisons. The SMEs provided their assessment of how the EMs compared against each other using the verbal scale and the numerical scale in Figure 41.

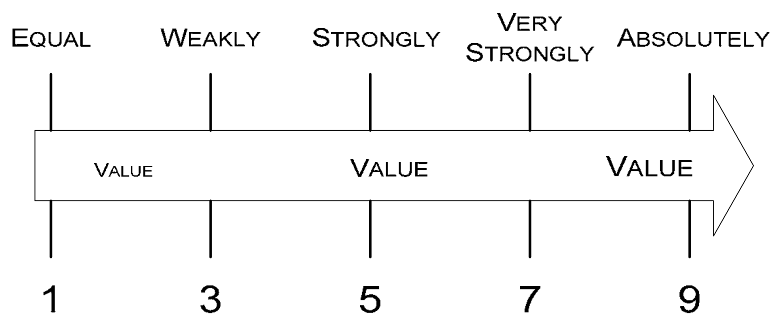


Figure 41. Sample Analytical Hierarchy Process Scale.

This scale ties the numerical AHP values to the verbal equivalents utilized during the JC3M stakeholder questionnaire. This sample scale ranges illustrates the range of potential values from one ninth as valuable to nine times as valuable.

A value of 1 signifies the objectives were equal; 3 signifies an objective was weakly superior to the other objective; 5 signifies an objective was strongly superior; 7 signifies very strongly; and 9 signifies absolutely superior. Objective measures are compared pairwise, i.e. Percentage of Traceable Measures is strongly superior (5) to Days to Plan Evaluation. The AHP then attributed a relative weight of 5 to Percent Traceable Measures and a relative weight of 1 to Days to Plan Evaluation. The reciprocal comparison is also recorded in the cell on the opposite side of the diagonal; Days to Plan Evaluation is 1/5 with respect to Percentage of Traceable Measures. The relative weights remain the same; it is only the order of measures that changes.

This assessment resulted in some inconsistent weighting of the objectives. This is not too unusual for the first iteration in trying to quantify the relative importance of the different evaluation measures. As this inconsistency was discovered after the SMEs were no longer available, the team did not have the opportunity to re-engage the SMEs in order to resolve those inconsistencies. The degree of inconsistency of the pairwise comparison matrix exceeded 0.1. Nevertheless, the team performed an eigenvector calculation on the responses. An eigenvector is a mathematical term encountered when studying linear transformations. In AHP, the result of the eigenvector calculation provides the weights for each EM. Saaty [1994] demonstrated mathematically that the eigenvector solution was the best approach to obtain weights from the AHP matrix. Equation 4 can be treated as an eigenvector problem and is solved for w to obtain the weights.

$$\mathbf{A}\mathbf{w} = \mathrm{n}\mathbf{w} \tag{4}$$

where **A** is the AHP matrix, **w** is the eigenvector and w_i is the weight of EM_i, and n is the dimension of the matrix and the eigenvector. Equation 4 is the Eigenvalue equation expressed as a matrix.

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n1} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{5}$$

In Equation 5 solving for **w** yields the weights for each evaluation measure [Ishikawa, 2007], shown in Table 15.

	Percentage of Traceable Measures	Days to Plan Evaluation	Quality of Planning Outputs	Elasticity of Labor	Elasticity of Duration
EM Weights	**0.248**	**0.058**	**0.419**	**0.084**	**0.192**

Table 15. AHP Evaluation Measure Weights.

The weights are calculated using an iterative eigenvector process.

A sensitivity analysis on the effect of the weights was performed. The conclusion is that the noted minor inconsistencies do not invalidate the final results. Based on sound reasoning, the results of applying these weights to the utility scores have resulted in valid relative rankings of the alternatives even though the absolute values used to populate the quantitative decision matrix would differ slightly if the weights were changed.

F. RAW DATA VALUES

This section summarizes the raw data values obtained through modeling and simulation and offline evaluation.

1. Results of Percent Traceable Measures EM

Percentage of Traceable Measures (PTM) was the EM for the Define Measures (1.3.2) function of the JC3M value hierarchy. The objective of the Define Measures function was to determine how well an alternative identified measures of performance

(MOP) when evaluating the SoS. An EM should not be confused with a MOP. EMs are measures created by the team to gauge functions of the JC3M system. MOPs are measures that gauge performance of a C4I SoS. The detailed methodology used to derive the PTM EM is included in Appendix G. The results are also summarized in this section.

Definition of PTM:

This EM was calculated by dividing the number of measures (traceable to stakeholder requirements) generated by the alternative, by the number of measures generated by the alternative

$$PTM = \frac{\#\,Traceable\,Measures\,Created}{\#\,Total\,Measures\,Created} \tag{6}$$

However, the team came to the conclusion that it was not feasible to calculate the PTM EM as it was defined because that would entail exercising each of the alternative systems and developing MOPs for each alternative. Therefore, a proxy measure was developed that could serve as an indicator to the performance of the Define Measures function.

Proxy Definition of PTM:

This EM was calculated by taking the number of authoritative sources that were considered in the process and then dividing by the total number of authoritative sources available for the SoS.

$$PTM = \frac{\#\ Authoritative\,Sources\,Considered}{\#\ Authoritative\,Sources\ Available} \tag{7}$$

The concept was that analysts performing the Define Measures function should consider all available documentation for the SoS. Considering all available documentation helped to ensure that all requirements and testable capabilities are captured in the process and subsequently MOPs are defined for each. The team considered that in reviewing a wider set of authoritative sources the process would yield a higher number of requirements and capabilities, and in turn provide more traceable metrics.

If an alternative considered every document in the comprehensive list of authoritative documents, as discussed in Appendix G, it received a score of 100%. Table 26, in Appendix G, contains the comprehensive list of authoritative documents, weights for each document, and the score for each alternative. If an alternative uses a document in its process then the alternative receives the complete score for that document. The final results of the PTM EM is included in Table 15.

2. Results of Quality of Planning Outputs EM

Quality of Planning Outputs was the EM for the Planning Results (1.4.3) function of the JC3M value hierarchy. The objective of the Planning Results function was to determine how well an alternative produced planning documents when planning for a C4I SoS evaluation. This EM was calculated by assigning an overall quality level to the planning documents produced by the alternative. The detailed methodology used to derive the Quality of Planning Outputs EM is included in Appendix C. However, the results are also summarized here. The results of the Quality of Planning Outputs EM are included in Table 16.

The JC3M team decided to use a Likert scale to determine the quality of planning products evaluation measure. The Likert scale was set from 1 to 4 with four being the best score and one being the worst score.

The team assembled a questionnaire (provided at Appendix C) that reviewed the quality of planning products. Each question also contained a criterion in order to help the respondent differentiate between a best value of 4 or a worst value of 1.

After creating the questionnaire the team solicited SME input. One SME from MCTSSA, and two from China Lake, answered the questionnaire.

The raw score was calculated by averaging the scores for each alternative from the questions answered by each of the SMEs.

3. Compiled results for all EMs

Table 16 depicts the results including both M&S and offline evaluation, which provided values to express the performance of the alternatives for every critical EM. (Cost is calculated separately.)

	Percentage of Traceable Measures (%)	**Days to Plan Evaluation (Days)**	**Quality of Planning Outputs (1-4 Likert Scale)**	**Elasticity of Labor (unit less)**	**Elasticity of Duration (unit less)**
Ideal Value	**100%**	**Less is better**	**4 is Ideal**	**Less is better**	**Less is better**
FEDOS	0	140	3.17	0.87	0.87
MC3T	72	121	3.25	0.78	0.78
JTEM CTM	92	73	3.42	1.04	0.83
SCR	92	158	3.00	0.98	0.98
FCB	88	127	2.75	0.72	0.72

Table 16. Raw Data Matrix.

This is the Raw Data Matrix with the raw scores for each EM. The results are the raw scores that are still in the units of the respective EM. Scores for all alternatives were rounded for display in this table.

G. CALCULATING AN OVERALL UTILITY SCORE

As stated in Section B “Multi Attribute Utility Theory” of this Chapter, the EMs are combined into a single measure for each alternative called the overall utility score. Equation 2, the value function equation, was used to calculate the overall utility score. Table 17 and Table 18 depict the intermediate and final values obtained using the equation.

Table 17 depicts the EMs after transforming the raw score into the utility score using the Wymorian SSFs. A utility score of 1.0 is ideal.

	Percentage of Traceable Measures	**Days to Plan Evaluation**	**Quality of Planning Outputs**	**Elasticity of Labor**	**Elasticity of Duration**
Range	**0 – 1**	**0 – 1**	**0 – 1**	**0 – 1**	**0 – 1**
FEDOS	0.00	0.66	0.92	0.75	0.75
MC3T	0.10	0.88	0.94	0.86	0.86
JTEM CTM	0.98	1.00	0.96	0.42	0.80
SCR	0.98	0.37	0.89	0.54	0.54
FCB	0.90	0.83	0.82	0.92	0.92

Table 17. Utility Score Data Matrix.

This is the Utility Score Data Matrix with the utility scores for each EM. The results are the individual utility scores that range from 0 to 1, where 1 is ideal. Scores for all alternatives were rounded for display in this table.

After obtaining the utility scores, the scores are then multiplied by their respective weights. Finally, the overall utility score is obtained by adding the individual EM weighted utility scores for each alternative. The individual EM weighted utility scores, overall utility scores, and LCCE (in millions of dollars) for each alternative are recorded in Table 18.

	Percentage of Traceable Measures	Days to Plan Evaluation	Quality of Planning Outputs	Elasticity of Labor	Elasticity of Duration	Overall Utility (0 – 1)	LCCE ($ Mil)
FEDOS	0.00	0.04	0.39	0.06	0.14	0.63	5.01
MC3T	0.02	0.05	0.39	0.07	0.17	0.71	5.98
JTEM CTM	0.24	0.06	0.40	0.04	0.15	0.89	6.97
SCR	0.24	0.02	0.37	0.05	0.10	0.79	7.72
FCB	0.22	0.05	0.34	0.08	0.18	0.87	8.13

Table 18. Quantitative Modeling Decision Matrix.

This table displays the estimated performance of each alternative as weighted utility scores for each EM. The weighted utility scores are summed and displayed adjacent to the LCCE (in millions) in the yellow columns. Weighted Utility and Overall Utility scores for all alternatives were rounded for display in this table; these rounded values were used for Figure 42 and Figure 43.

H. UTILITY SCORE VERSUS LIFE CYCLE COST ESTIMATE

The final step of AoA was to compare alternatives side by side using a Utility versus Life Cycle Cost Estimate Plot (see Figure 42 and Figure 43). The plot allowed decision makers to visually compare the cost of each alternative, the estimated performance of each alternative, and the cost to achieve estimated performance in specific alternatives simultaneously. This data was utilized in the Final Recommendation phase, where a summary of the project results was provided for stakeholder consideration. Figure 42 and Figure 43 are similar; Figure 43 is scaled to increase the ability to differentiate the relative cost and performance of each alternative.

FCB has the highest LCCE at $8.13M. SCR is next at $7.72M, followed by JTEM CTM which costs $6.97M. FEDOS and MC3T follow with LCCE of $5.01M and $5.97M respectively. JTEM CTM and FCB dominate all of the other alternatives for utility with scores of 0.89 and 0.87. JTEM CTM and FCB have virtually equal utility, yet the JTEM CTM LCCE costs approximately $1.16M less than FCB. JTEM CTM has the median LCCE of the five alternatives which, coupled with the highest utility, clearly dominated all other alternatives.

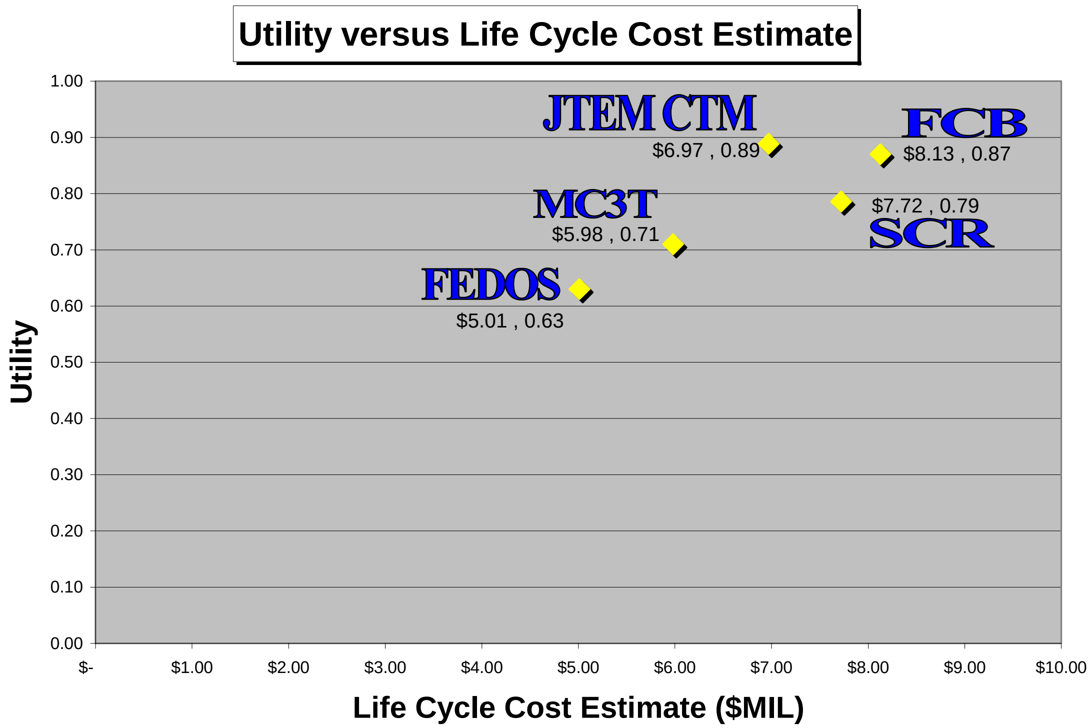


Figure 42. Utility versus Life Cycle Cost Estimate Plot.

This plot illustrates the utility of each alternative while displaying the estimated cost to achieve that performance. JTEM CTM utility slightly exceeded that of the FCB alternative, with scores of 0.89 and 0.87 respectively. JTEM CTM and FCB utility scores are followed in descending order by SCR, MC3T, and FEDOS. LCCE values (in millions) range from FEDOS at $5.01 to FCB at $8.13. JTEM CTM has the median LCCE value at $6.97.

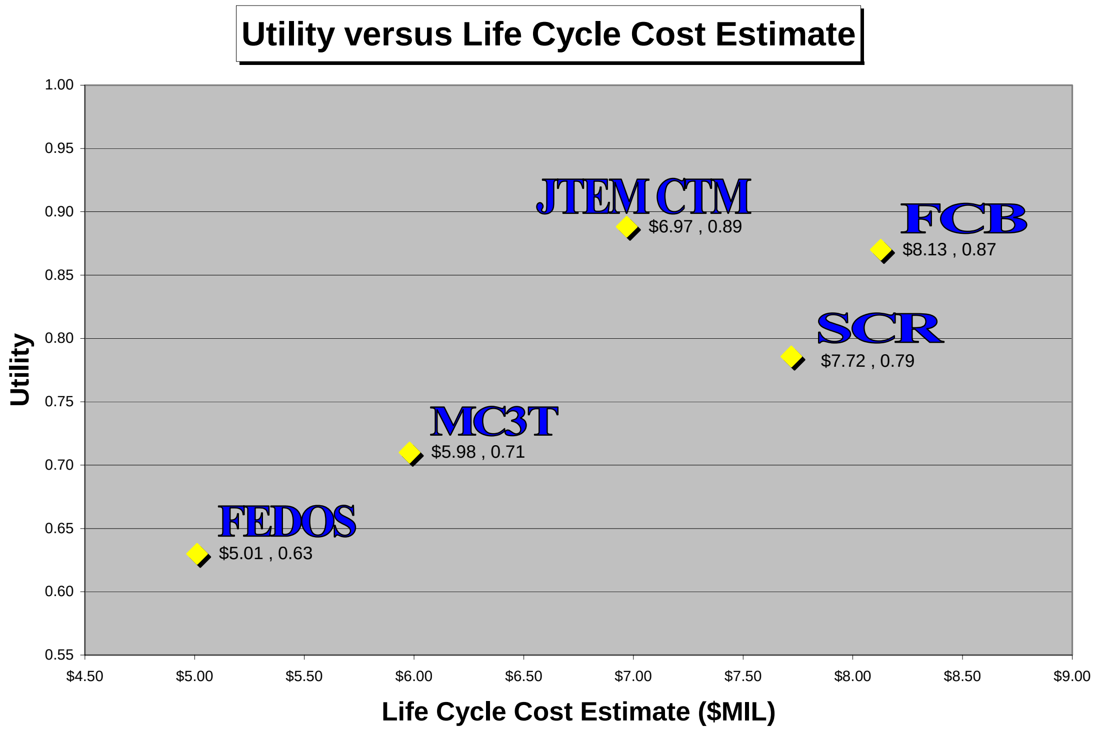


Figure 43. Utility versus Life Cycle Cost Estimate Plot Zoom.

This plot illustrates the utility of each alternative while displaying the estimated cost to achieve that performance. FEDOS had the lowest estimated utility, followed by MC3T, SCR, FCB, and JTEM CTM. JTEM CTM and FCB scored 0.89 and 0.87 respectively. FEDOS had the lowest estimated cost, followed by MC3T, JTEM CTM, SCR, and FCB. JTEM CTM slightly exceeds the other alternatives for utility, and has the median cost of the five alternatives. This figure differs from Figure 43 in that the scale is revised, with the origin at $4.5M, 0.55 utility in order to more clearly demonstrate the differences between alternatives.

VII. FINAL RECOMMENDATIONS AND CONCLUSIONS

A. PERFORMANCE ANALYSIS

The JC3M team determined the highest performance was exhibited by the JTEM CTM alternative, at an overall utility rating of 0.89 on a 1-0 scale. In order of decreasing utility, the other alternatives were FCB at 0.87; SCF at 0.79; MC3T at 0.71; and FEDOS at 0.63.

The team's confidence in the accuracy of the performance evaluations differed among the alternatives. The team had very high confidence in the accuracy of the performance evaluation of MC3T and FEDOS. The team had less, although still high, confidence in the accuracy of the JTEM CTM performance evaluation. The team had less confidence in the accuracy of the performance evaluation of FCB and SCR.

Of all the alternatives considered, the team had the most confidence in the estimates of performance calculated for both MC3T and FEDOS. These are the only two alternatives that had been utilized in the conduct of full-scale C4I SoS evaluations. This real world use of the two alternatives (MC3T and FEDOS) meant the team was able to review historical records of actual inputs and outputs of the alternatives, and observe the duration of each of these alternatives. Given the number of data sources and recent nature of this data, while MC3T was implementing their processes as the JC3M team was analyzing alternative solutions, the team had confidence in the accuracy of the estimate of performance from these two alternatives. The team has observed first hand the type, scope, and duration of efforts involved in MC3T, which are reflected in the overall utility score of the alternative, and concluded MC3T will deliver better utility than FEDOS.

While the JTEM CTM has not been used for full scale C4I SoS evaluations, it is the alternative in which the JC3M team had the next greatest confidence in the accuracy of the performance evaluation. The JTEM CTM has been reviewed by a very large group of stakeholders, the JTEM Community of Interest (COI). These C4I SoS experts have provided input to the JTEM CTM methods and processes. A subset of the COI participated in the JTEM "Rock Drills" which included a series of tabletop exercises used to evaluate and refine the JTEM CTM. JTEM CTM members have participated in the definition and development of JC3M. They have explicitly validated the content and definition of the subset of JTEM CTM tasks which were identified as a JC3M alternative solution. This validation included a review of the scope, tasks, components, duration, and resources required for JTEM CTM to perform a JC3M C4I SoS evaluation. Because of the COI review, Rock Drills, and performance validation through modeling of the JTEM CTM; the JC3M team has confidence in the accuracy of the estimate of performance of this alternative, albeit at a lesser level than the real-world performance of both FEDOS and MC3T.

The team had less confidence in the accuracy of the performance evaluation of the SCR and FCB alternatives. Neither of these alternatives benefited from the very extensive C4I SoS SME review which supported JTEM CTM. Additionally, neither alternative has been used in real world SoS evaluations, unlike FEDOS and MC3T.

B. COST ANALYSIS

The JC3M team determined the least expensive alternative was the FEDOS alternative, at a life cycle cost of $5.01M over the ten-year projected lifespan of JC3M. In order of increasing cost, the other alternatives were MC3T at $5.98M; JTEM CTM at $6.97M; SCR at $7.72M; and FCB at $8.13M.

The team noted that MC3T was estimated to cost approximately $970,000 more than FEDOS, which it has replaced, over the ten year span of the LCCE. Because the LCCE postulated the conduct of a single C4I SoS evaluation per year through the eight year O&S phase, this cost difference equates to approximately $121,000 per C4I SoS evaluation.

The team also noted that FCB is approximately $410,000 more than SCR. Unique to FCB is the use of senior SMEs who generate the performance measures, yet are not part of the organization conducting the C4I SoS evaluation. The team calculated the cost of senior SMEs, and included these as an overall cost to DoD. While the cost of their labor was not charged to C4I test organizations, the use of these resources is a cost to DoD. If the cost of only personnel organic to the test organization had been reported for FCB, the cost would have been lower by $1.14M but this would have represented only part of the cost of DoD resources.

In a discussion with the Deputy Chief of the Methods and Processes Division [Wilson, 2007], the team reviewed the maturity of the JTEM CTM and its readiness for implementation. While JTEM plans to deliver two more versions of the CTM by 2009, the development between 2007 and 2009 is primarily focused on development of the Joint Mission Environment. Wilson [2007] and the JC3M team lead agreed that the CTM was robust in its current state, but would require additional development.

The cost to complete development of the JTEM CTM [Bjorkman (b), 2007], is approximately $3.5M through 2009. Although the team included the complete development cost of the JTEM CTM in the LCCE, they recognized that development is a non-recurring cost that is not borne by any C4I test organization.

O&S is the most important cost from the perspective of C4I test organizations. O&S is a recurring cost, borne by each C4I test organization that implements an alternative, for each year that alternative is used. With the exception of the JTEM CTM development cost ($3.5M), O&S is the largest portion of the LCCE for each alternative. The JTEM CTM alternative had the lowest overall O&S cost at $2.25M over the ten year LCCE. This O&S cost was the lowest of all alternatives by $1.66M.

Of all the alternatives considered, the team had the most confidence in the cost estimates of both MC3T and FEDOS. The team was able to review historical records of the planned and actual costs of each of these alternatives: the confidence in these cost estimates was high. The team had the next highest confidence in the cost of the JTEM CTM alternative. The team validated their cost model with the JTEM and included the actual funding required to complete the JTEM CTM development in the LCCE. The team had less confidence in the cost estimate of the SCR and FCB alternatives. Neither of these alternatives have been used in real world SoS evaluations, unlike FEDOS and MC3T. Additionally, the models for SCR and FCB are simply estimates and have not been validated as in the case of JTEM CTM.

C. PERFORMANCE VERSUS COST ANALYSIS

As stated previously, the JC3M team determined the performance and cost of each alternative to be as follows: JTEM CTM at 0.89 and $6.97M, FCB at 0.87 and $8.13M; SCR at 0.79 and $7.72M; MC3T at 0.71 and $5.98M; and FEDOS at 0.63 and 5.01M.

The team was interested to observe stratification in performance ratings; MC3T and FEDOS were relatively close in both cost and utility; FCB and SCR were similarly close; and all four of these alternatives can be seen to deliver increased utility in return for increased cost.

The slope of the line expressing the relationship between cost and utility is 0.070847, where a change in cost results in a change in utility. The equation for calculating the slope of the regression line *b* is given by

$$b = \frac{\sum\left(x - \bar{x}\right)\left(y - \bar{y}\right)}{\sum\left(x - \bar{x}\right)^2} \tag{8}$$

where *x* represents the cost value of a specific alternative, and $\bar{x}$ the average of the cost values, where *y* represents the cost value of a specific alternative, and $\bar{y}$ the average of the utility values [Baker, 2006: 6]. The regression line (L_1) can be seen in Figure 44.

Had the team considered alternatives as a portfolio, and combined attributes (the C2 SME panel from the FCB alternative, for example, with the MC3T use of Service stakeholders) it would have been possible to define mixed-attribute alternatives that provided more utility for the same cost. The most cost-effective combinations would have formed a curved efficient frontier [Gunser, 2004: 26] of utility for every level of cost. Because combinations were not considered, a linear efficient frontier (L_2) is defined by the three more efficient alternatives and is seen in Figure 44. Given their respective utility scores, both the FCB and SCR alternatives are to the right of the frontier, less efficient than, and dominated by, the JTEM CTM alternative.

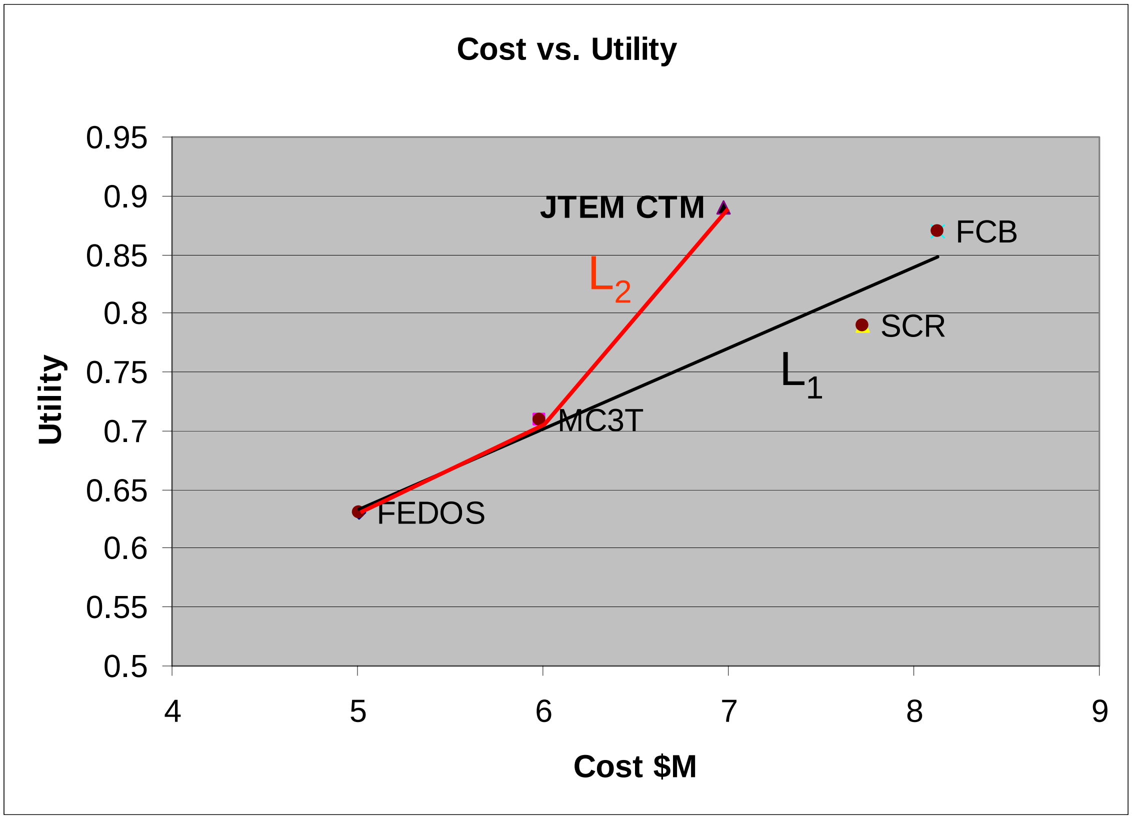


Figure 44. Cost Versus Utility with Trendline.

The figure illustrates estimated LCCE and performance values for the five alternatives. The LCCE and performance values for four alternatives (FEDOS, MC3T, SCR, and FCB) were used to generate a trendline to predict performance based on alternative cost. With this trendline, the predicted performance of JTEM CTM is greater than what would be expected, based on the JTEM CTM LCCE. The JTEM CTM alternative is above the predicted performance value (L_1), indicating it has a higher value to cost ratio than other alternatives. An efficient frontier (L_2) depicts the relative inefficiency of FCB and SCR when compared to JTEM CTM.

D. CONCLUSION

The JTEM CTM alternative dominated both FCB and SCR, providing higher estimated utility for less cost. JTEM CTM exceeded the performance of all alternatives by a very slight margin. Though the team had different levels of confidence in the utility scores of each alternative, they are confident that the results and conclusions are valid. As described in section A, the team had more confidence in the JTEM CTM utility score than in the next highest alternative, FCB.

The JTEM CTM had the median LCCE, and the lowest O&S cost by a large margin. Chapter V section A.2.b “Operations and Support Costs” noted that costs in the

O&S phase were primarily driven by the use of personnel resources. The 73 day duration of the JTEM CTM planning phase led to the smallest O&S cost. The next alternative, MC3T, had a 121 day planning phase, with correspondingly higher O&S costs. This is significant because O&S is a recurring cost, borne by every C4I test organization that utilizes an alternative. Development of JTEM CTM is the largest portion of the LCCE for this alternative. However, the development of JTEM CTM is a nonrecurring cost borne by OSD and not borne by any C4I test organization.

The team recommends monitoring the development of the JTEM CTM for further maturation. The JTEM CTM promises significant improvements in the overall utility of C4I SoS evaluations, at a significantly reduced operating cost, and deserves further investigation. The scope of this project, however, does not allow that investigation. The team recommends detailed investigation of the JTEM CTM in its entirety, and optimizing of personnel resources and organizations with a modeling tool such as POW-ER. The team also recommends for JTEM CTM to conduct a C4I SoS evaluation as soon as feasible, to validate the JTEM CTM methods and processes in a "real world" event.

E. AREAS FOR FURTHER STUDY

The JC3M team identified several SoS issues in the course of the project, and recommended investigation of selected issues when additional time is available.

1. Establish a Manager

The team believed the C4I acquisition and testing communities would benefit from a dedicated Joint C4I SoS manager. A dedicated SoS manager could provide consistency of knowledge in an evolving C4I acquisition and testing environment. Their role could include, but should not be limited to, the following tasks: Documenting C4I SoS capabilities, long range SoS capabilities planning, testing requirements management, reducing SoS testing cycle and costs, assessing the improvements in SoS processes, supporting developmental and operational testing as a stakeholder, actively participating in IPTs that address SoS testing issues, risk management, and addressing ad hoc SoS configuration resulting from new threats and concepts. This is consistent with the concepts of capability portfolio management under the Joint capabilities area construct.

2. Initiate Risk Management Strategies

The C4I SoS continues to change configuration as it exhibits new capabilities. The continually changing architecture of the C4I SoS increases the probability of capability failures. The increasing probability of capability failures creates risks that need be managed. The JC3M team believes risk management strategies should be developed and applied to the C4I SoS. The JC3M team has compiled a preliminary list of risks that should be managed across the C4I SoS, including the lack of a single entity responsible for SoS performance; lack of an objective, repeatable, and methodical approach to address individual system problems that impact SoS functionality; varying levels of maturity of critical systems within the C4I SoS architecture; lack of consistent SoS integration of individual systems; and varied interfaces between individual systems that comprise the C4I SoS.

3. Modify the Acquisition Process

Systems that are components of the C4I SoS have their capabilities defined as if they exist in a vacuum, and their impact on C4I SoS capabilities is not considered. System level capabilities should be considered in light of their effect on the C4I SoS, which is consistent with the concept of capability portfolio management. The DoD C4I SoS acquisition process should require component system sponsors to define C4I SoS level effects when creating CDDs and CPDs; establish a funding process for SoS testing; require systems to identify their effects on the C4I SoS before fielding; include end-to-end SoS effectiveness testing as an explicit part of Operational Testing

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APPENDIX A. PROJECT PLAN

INTRODUCTION

This is the Project Management Plan (PMP) for the capstone project to be completed by the Marine Corps Tactical Systems Support Activity (MCTSSA) Cohort in the Naval Postgraduate School (NPS) Masters of Science in Systems Engineering program. The Joint Command, Control, Communications, Computers, and Intelligence (C4I) Capability Certification Management (JC3M) project will create a system for certifying the capability of a C4I System of Systems (SoS). A System of Systems in the context of this project is a group of individual C4I systems, which may not have been designed, acquired, or managed as a collective enterprise, but are being put together as such and forming an interdependent entity. The JC3M system is intended to perform an assessment that will identify the desired war fighting capabilities and ensure that the SoS under test meets these requirements in the intended environment.

PROJECT DESCRIPTION

Across the Department of Defense (DoD), early C4I systems were designed, acquired, and fielded independently, each addressing a single warfighting function, such as logistics, fire support, or intelligence. Over time, warfighting has grown in complexity, tempo, and scope, so organizations must be able to respond with increased agility across greater distances. This complexity is compounded by adaptive and elusive adversaries. To combat today's adversaries, DoD forces fight jointly.

Individual C4I systems, which may not have been designed, acquired, or managed as a collective enterprise, are being put together as such and forming an interdependent entity, a SoS. Today's C4I SoS, whether Joint or Single Service, is required to transport and process shared data throughout the operating forces. Problems are abundant because there is no baseline, standard configuration, or overall management of the SoS.

C4I system-level acquisition, testing, and management are well understood, and individual systems have performance requirements. However, ever-changing configurations of C4I SoS may not have formally established performance requirements, nor threshold values that can be used to evaluate performance. There is not a clear understanding of how to manage or assess C4I SoS performance or C4I SoS capability to support Joint or single Service missions. A C4I SoS-level capability is a task achievable by multiple enterprise components that is not achievable by a single enterprise component working on its own. Examples of C4I SoS capabilities include Call for Fire, Immediate Close Air Support, and Building a Common Operational Picture. Processes and methods for designing and executing C4I system tests are well defined and executed, but testing at the SoS level is not well defined, nor are consistent standards and practices applied. A complicating factor is that real instances of the C4I SoS have a practically infinite number of possible configurations.

The Joint Interoperability Test Command (JITC) tests the interoperability of systems, but this proves that system interfaces function. There is no agency that assesses the capability of a SoS to accomplish a task that requires the coordinated, successful integration of functions and interfaces across multiple systems. The Marine Corps, for example, has extensive doctrine for the conduct of artillery fire support, but there are not documented, testable values which can be used to assess the success of a fire mission. If a Forward Observer (FO) had to initiate a Call For Fire five times, did the C4I SoS demonstrate a successful capability to provide fire support? What if the FO had to try seven times? Three times? What constitutes success? This lack of a consistent SoS performance requirement process bedevils all of DoD.

JC3M system is important because it provides the acquisition community much-needed performance requirements for the design of new systems, integration of legacy systems, and SoS testing. JC3M system is also important because it provides system integrators a tool to assess integration formally, it documents system capabilities and construction, and it provides confidence to the warfighter that the C4I SoS works. Every C4I SoS has been custom built to date, with all the Configuration Management (CM), troubleshooting, training, and support challenges this "one-off" approach implies. With a consistent assessment methodology and a documented baseline configuration, C4I SoS support becomes repeatable, and CM, training, troubleshooting, and knowledge management costs shrink.

The Joint Test Evaluation Methodology (JTEM) team is addressing Joint SoS interoperability from the Office of Secretary of Defense (OSD) level. Marine Corps Systems Command (MARCORSYSCOM), the acquisition organization for the Marine Corps, is approaching the issue from a Service perspective. MARCORSYSCOM has tasked MCTSSA to develop Marine Air Ground Task Force (MAGTF) C4I Capability Certification Management (MC3T), a methodology for managing the MAGTF C4I SoS as a single system, in accord with modern systems engineering practices. MC3T will manage the MAGTF C4I SoS as a set of SoS-level capabilities, rather than as a fixed hardware or software baseline.

The JC3M project team will define a system that will assist a test agency in performing a C4I SoS assessment that will identify the desired war fighting capabilities and ensure that the system under test meets these requirements. The JC3M system will include Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) considerations in designing the system to be used by an organization, following repeatable processes, and consistent resources. The processes will not only be usable by MC3T, but can, with appropriate Service-specific modifications, be utilized by other Services and Joint agencies.

ORGANIZATION

The JC3M project team organization is provided in Figure 45.

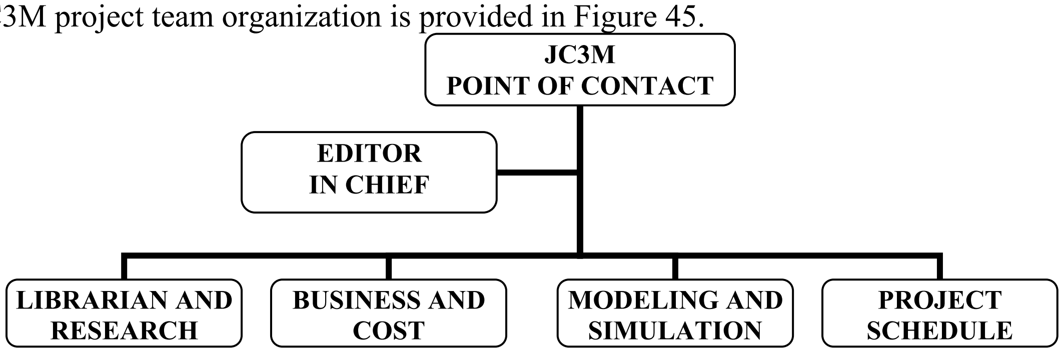

Figure 45. JC3M Team Organization.

Roles & Responsibilities

The JC3M project team consists of 14 interdisciplinary team members located in 5 different geographical locations. Table 19 is a listing of each team member's roles and responsibilities. Roles and responsibilities are subject to change as the project progresses.

Name	Roles & Responsibilities	Location
Lamb, Jeremy	Librarian & Researcher	Bethesda
Martin, Calvin	Meeting Minutes, Librarian & Researcher	China Lake
Acosta, Jacobo	Business &Cost	Corona
Huseth, Scott	Meeting Minutes, Business & Cost	Corona
Medina, Vince	Business & Cost, Modeling & Simulation	Corona
Trinh, Khai	Modeling & Simulation	Corona
Hoesly, Scott	Meeting Minutes, Business & Cost	MCTSSA
Medina, Jorge	Business & Cost	MCTSSA
Nguyen, Michael	Librarian & Researcher	MCTSSA
Patel, Jay	Project Schedule, Librarian & Researcher	MCTSSA
Rangi, Kamaljit	Librarian & Researcher, Modeling & Simulation, Project Schedule	MCTSSA
Schoen, Tim	Librarian & Researcher, Modeling & Simulation	MCTSSA
Willis, Ron	POC, Business & Cost	MCTSSA
Krider, Steven	Editor in Chief	Philadelphia

Table 19. Team Member Listing.

Project Advisors

The JC3M project team advisor is Gregory Miller. The second reader is Professor David Hart. Both are NPS faculty members in the Department of Systems Engineering.

APPROACH FOR PMP UPDATES

The JC3M project team will review the PMP throughout the NPS Capstone project. If significant discrepancies or errors are found during a review, the PMP will be updated. The Editor in Chief will incorporate the changes and submit the revised PMP to the Capstone Advisor for review and approval. If a change in scope or engineering approach induced the revision, the JC3M project team will resubmit the PMP to the Systems Engineering Department Chair for approval.

CONFIGURATION MANAGEMENT

The deliverables created by the JC3M project are in the form of documents, presentations, and simulation results. The Editor in Chief will maintain a copy of all deliverables and deliverable revisions in a chronological archive. The JC3M project team will revise each of the deliverables prior to being finalized for submittal. This JC3M project team edits will be tracked utilizing a system of incremental alphanumeric revisions (i.e. PMP Rev A to PMP Rev B). Once a deliverable is ready for submittal it will be published utilizing numeric revision (i.e. PMP Rev 1).

TECHNICAL REVIEWS

The JC3M project team will employ technical reviews as a way to ensure accuracy, validity, and appropriateness of progress. Work products will be reviewed internally and by stakeholders to ensure all parties understand the problem, the approach, and the solution. Technical reviews precede formal control gates, set expectations for all stakeholders, and reduce the number of surprises at formal reviews.

SYSTEMS ENGINEERING APPROACH

OVERVIEW

The JC3M project team will implement a Systems Engineering approach that starts with the identification of customers' needs and proceeds through the phases illustrated in Figure 46 until a recommended solution is generated. Each phase presents the opportunity to re-evaluate progress and return to a prior stage for refinements if necessary. This will be critical to adapting the project to ensure the customers' and stakeholders' needs are being achieved. The SE process model below is based on combination of System Engineering Design Process (SEDP) by Prof Paulo and SIMILAR System Engineering Process Model from INCOSE, modified to fit this project.

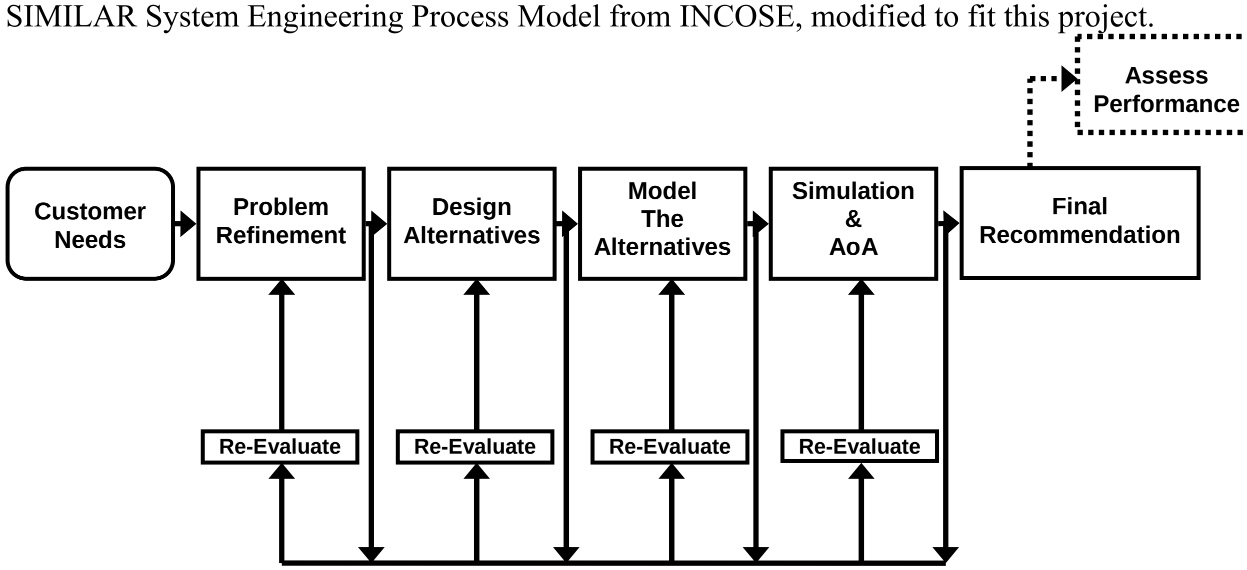

Figure 46. JC3M Systems Engineering Process.

JC3M Systems Engineering Process Phases

Each of the JC3M Systems Engineering Process phases is explained herein.

Problem Refinement Phase

The JC3M project team will utilize this phase to clarify the customer's needs and begin managing the JC3M project risks. The outputs of this phase will allow the JC3M project team to design multiple solutions for the JC3M system problem. The Problem Refinement Phase is composed of four key elements described below.

Element 1: <u>Needs Analysis</u>
This element will provide justification for proceeding further in the design process. It will perform System Decomposition in order to gain an initial understanding of the process in question and to begin to look at the process in terms of how it fits into the "big picture", and Functional Analysis in order to identify and decompose the critical function(s). It will take primitive needs elicited during stakeholder analysis and transforming them into effective needs. If conflicts occur, compromise will be sought after when possible, however, key stakeholders such as JTEM and the NPS Systems Engineering Department will have stronger influence than others.

<u>Inputs:</u> Initial Problem Statement, Stakeholders Needs/Wants
<u>Tools:</u> Functional flow diagrams
<u>Outputs:</u> Revised Problem Statement

Element 2: Requirement Generation and Analysis
During this element, the JC3M project team will generate a set of processes that reflect stakeholders' needs. Requirements analysis will assists the customers in refining their requirements in concert with defining functional requirements. Stakeholder Analysis will also be performed to identify people and organizations relevant to our problem and to determine their needs, wants and desires. Stakeholders will have a vested interest, or personal stake, in our problem and/or its eventual solution.

<u>Inputs:</u> Revised Problems Statement
<u>Outputs:</u> Initial Problem Refinement Report (PRR), Functional Hierarchy

Element 3: Value System Design
The JC3M project team will use this element to help establish processes, objectives, and evaluation measures. Value System Design will establish a qualitative value hierarchy tree that identifies processes, objectives and sub-objectives, and evaluation criteria. Value System Design will identify system characteristics that reveal measurable parameters. These parameters will identify the metrics for evaluation of alternative solutions. Measures of Effectiveness (MOE) and Measures of Performance (MOP) will be generated from the value hierarchy tree. MOEs will reflect operational objectives and be understandable to decision-makers. MOPs will provide measurable results that can demonstrate progress towards goals and objectives, provide specific measurement results, and determine effectiveness. MOPs will determine if the system is meeting its mission, vision, and goals.

<u>Inputs:</u> Initial PRR
<u>Tools:</u> Value Hierarchy Tree
<u>Outputs:</u> MOEs, MOPs

Element 4: *<u>Initiate Risk Management</u>*

The JC3M project team shall Initiate Risk Management by identifying potential opportunities for risks, assessing their associated probabilities of occurrence, and determining their impact to the project. Risk management will address:

Requirements risk – The JC3M project team will identify and describe the requirements of JC3M system with stakeholders, and aggressively manage the scope of requirements to minimize scope creep.

External risks – Is the process development dependent on external events or accomplishments over which the program has no control?

Development risk – Can the process be designed so that required function and performance are met within constraints?
Resource availability – Are required personnel and facilities available?
Resource risks – Are funding, training, schedule (time) and tools available?
The JC3M project team will manage these risks by developing and documenting a risk management strategy. This strategy will include risk planning, assessment, handling, and monitoring. For each identified risk item, probability/consequence scales will be developed and ratings will be assigned. Supporting analysis will help rate, prioritize, and aggregate risks in order to minimize potential areas of concern. This analysis will be conducted in accordance with the Risk Management Guide For DoD Acquisition.

Design Alternatives Phase

The JC3M project team will utilize the Design Alternatives Phase to generate multiple solutions to the problem, establish feasibility criteria and apply those criteria to eliminate those alternatives that are clearly infeasible. The creation of these solutions requires the outputs of the Problem Refinement Phase. The outputs of this phase will be used for the creation of models in the Model the Alternatives Phase and for the Analysis of Alternative (AoA) portion of the Simulation and Analysis of Alternatives Phase. The Design Alternatives Phase is composed of three key elements.

Element 1: Alternative Generation

In this element the JC3M project team will prioritize the critical functions and sub-functions that the system under design must be able to perform. These critical functions will be a subset of the functions defined in the Value Hierarchy during Value Systems Design. Next, the JC3M project team will brainstorm and research alternative ways to perform the critical system functions. Finally, the JC3M project team will build alternative packages that account for each function identified. Zwicky's Morphological Box (ZMB) will be used as a tool to develop the alternative packages. The output of this element will be a set of alternative solutions for the system under development.

<u>Inputs:</u> Value Hierarchy Tree, MOEs, MOPs, and PRR
<u>Tools:</u> ZMB, brainstorming, and research
<u>Outputs:</u> Set of alternatives

Element 2: Feasibility Screening

The purpose of this element is to eliminate from further consideration those alternatives that are clearly infeasible so as not to waste valuable effort in the Model the Alternatives Phase. First, screening constraints will be defined. Most of the screening constraints will come directly from the constraints on the system detailed in the Value System Design element of the Problem Refinement Phase. The JC3M project team will also obtain screening constraints from the stakeholders.

Those alternatives that meet all of the system constraints are considered feasible, while those that clearly fail to meet one or more constraints are considered infeasible. The screening process will only screen out those alternatives that are clearly infeasible. The JC3M project team will use a Feasibility Screening Matrix (FSM) to organize the results and identify the feasible alternatives.

<u>Inputs:</u> Set of alternatives, SRD, MOEs, MOPs, and Stakeholder input
Tools: FSM
<u>Outputs:</u> Feasible alternatives

Element 3: Alternative Scoring Criteria
The purpose of this element is to define the criteria for scoring alternatives based on MOEs and MOPs. Stakeholders must agree on the values that will be later used to score the final alternatives. Numbers quantify values and uncertainties; humans can understand, compare, and manipulate numbers. These criteria will be generated early, so stakeholders can review and validate them. Alternative scoring criteria provide quantitative support for the decision-makers and enables consistent evaluation of alternatives. The model that we will use is the quantitative value model. Quantitative value models are the scoring functions and weights that will be used during the Analysis of Alternatives to evaluate and compare our alternatives.
Input: Feasible alternatives, MOEs, MOPs, Value Hierarchy Tree
Output: Scoring Criteria, Preliminary Quantitative Value Modeling Decision Matrix

Model the Alternatives Phase

The JC3M project team will utilize this phase to generate models based on the alternatives selected in the Design Alternatives Phase. The outputs of this phase are the models of the alternatives that will be simulated during the Simulation and Analysis of Alternatives Phase. The Model the Alternatives Phase is composed of the two key elements described below.
Element 1: Model Development
Models will be developed based on the alternatives selected in the Design Alternatives phase in accordance with Department of Defense Architecture Framework (DoDAF), MAGTF, and Joint Services architectures. SoS interoperability diagrams based on legacy, current, and future systems will be utilized to create detailed functional and behavioral models.
Inputs: Feasible alternatives, DoDAF, Joint Service architectures, and Functional Hierarchy
Tools: Microsoft Visio and Vitech COREsim
Outputs: Detailed functional and behavioral models
Element 2: Cost Analysis
Based on the system requirements, the system life cycle, and activities in each phase of the life cycle, the Cost Breakdown Structure (CBS) will be developed and a life cycle cost estimate for each alternative will be developed. This will include a business model for the activity performing the test functions detailed in the final process.
Inputs: Detailed functional and behavioral models, existing cost data (stakeholders and others will be consulted for existing cost data)
Tools: Microsoft Excel and Operating and Support Cost Analysis Model (OSCAM)
Outputs: SoS Test Process Cost Estimates

Simulation and Analysis of Alternatives Phase

The JC3M project team will utilize the models generated earlier to evaluate and rank each of the alternatives. The output of this phase will provide a recommended solution to be published in the Final Recommendation Phase. The Simulation and Analysis of Alternatives Phase is composed of the two key elements described below.
Element 1: *Simulation*

The simulation model will be probabilistic, with elements of uncertainty as defined in the Problem Refinement Phase. The results from the simulation will provide a means of predicting or estimating the performance of our design alternatives with respect to the selected evaluation measures.
Input: Detailed functional and behavioral models
Tools: Vitech COREsim , SimVision and Arena
Outputs: Simulation results
Element 2: Sensitivity Analysis
The JC3M project team will utilize sensitivity analysis to determine the factors that contribute the most to variability in the simulation outputs.
Input: Simulation results
Outputs: Factors that contribute to the output variability
Element 3: Trade off Studies
Trade-off studies for the models and will be based on cost, schedule, and performance of each alternative.
Input: Simulation results
Outputs: Preliminary alternative ranking
Element 4: Analysis of Alternatives
This phase compares the alternative models, after their simulation performance, using MOEs, MOPs, and Quantitative Value Modeling Decision Matrix, to rank the alternatives. Once the structure and numbers are in place, and the stakeholders agree, the analysis can begin.
Inputs: Simulation results, factors that contribute to the output variability, scoring criteria, Preliminary Quantitative Value Modeling Decision Matrix, Preliminary alternative ranking
Tools: Quantitative Value Modeling Decision Matrix
Outputs: Ranked Alternatives

Final Recommendation Phase

The JC3M project team will assemble all earlier inputs into a cohesive recommendation for implementation, and publish this as a final report. The output of the Final Recommendation Phase will be provided to both the JTEM and MC3T teams for their use. The MC3T implementation team is a critical stakeholder, but their schedule includes a proof of concept event in October 2007. Based on this schedule, the MC3T team concluded they cannot wait for JC3M project outputs. MC3T will instead implement an interim process, and will review the JC3M project report for inclusion of applicable recommendations as MC3T refines their processes. The Final Recommendation Phase is composed of one key element described below.
Element 1: Publish Recommendation
In this phase, all outputs from earlier phases will be assembled into a final report. This report will be briefed and provided to stakeholders at the end of the project.
Inputs: Ranked Alternatives
Outputs: Final Report describing a recommended approach for the conduct of C4I SoS capability testing

Assess Performance Phase

This project will not completely conclude after delivery of the final report. Some members of the JC3M project team will continue to work with MC3T, JTEM, and other stakeholders after this project concludes. Some members of the team already participate in the JTEM Capability Testing Community of Interest, where they will share their experiences with other members and continue to advance the art of capability testing.

STAKEHOLDERS

Identification of stakeholders – organizations and personnel with an interest in, and some authority over, the final content of the project – is a critical task. Too few stakeholders can result in an incomplete problem assessment, with a resulting solution that is narrow. Too many stakeholders, with varying interests, can dilute the focus of the project, or increase the scope beyond the ability of the project team to address within a limited time. The project team will review the project history and description to identify stakeholders. The team will interview the stakeholders to validate their interest and authority, as well as to identify possible additional stakeholders.

The stakeholders are:

- NPS Systems Engineering Department will validate the appropriate problem and solution approach.
- JTEM team, Joint Test and Evaluation Project, is tasked to develop, test, and validate a methodology for defining, developing, and using a test environment to support test and evaluation of system performance in a Joint mission operational environment. JTEM reports through the Deputy Director, Air Warfare Operational Test and Evaluation, to Director, Operational Test and Evaluation (DOT&E) to the OSD. The JTEM lead is very interested in how both the JC3M project and MC3T solve some of the same challenges JTEM faces.
- MC3T team at MCTSSA, which may use the project output to modify their C4I SoS testing processes.
- Marine Corps Combat Development Command (MCCDC) is the agency that defines doctrine and requirements for the Marine Corps. MCCDC will be engaged in defining MAGTF C4I SoS requirements, and will be included in MC3T processes.

Possible additional stakeholders:

- Central Technical Support Facility (CTSF), Ft. Hood, TX, which performs many SoS tests for the U.S. Army, like MCTSSA, and may be interested in SoS test requirements generation and conduct.
- U.S. Army Test and Evaluation Command (ATEC), Alexandria, VA, plans, conducts, and integrates developmental testing, independent operational testing, independent evaluations, assessments, and experiments.
- U.S. Navy Operational Test and Evaluation Force (OPTEVFOR), Norfolk, VA, assesses the operational effectiveness and suitability of new and improved war fighting systems and capabilities for the Navy.
- JITC has the mission to provide operational test and evaluation of C4I systems, certify C4I systems interoperability and solve interoperability deficiencies.
- Air Force Operational Test and Evaluation Center, Kirtland Air Force Base, NM, assesses the capability of new systems to meet warfighter needs by planning, executing and reporting independent operational evaluations.

REQUIREMENTS

At this stage of the project, the JC3M project team knows that the system to be designed must be relatively affordable, flexible enough to work with a variety of SoS configurations, and relatively quick to execute. As defined in the process approach, refinement of requirements, as well as the possible discovery of new requirements, may affect a balanced, life-cycle solution. Additional requirements will be identified during the needs analysis element of the Problem Refinement Phase by conducting system decomposition, stakeholder analysis, and functional analysis, These requirements will be documented in the SRD that will be reviewed and approved by the stakeholders prior to the Design Alternatives phase.

TOOLS

The JC3M project team plans to utilize the tools identified in each phase and element during the execution of the project. However, the JC3M project team may determine that the identified tools are inadequate, unnecessary, or undesirable. If this occurs new tools will be researched and selected, if required, to complete the project elements.

RISK MANAGEMENT

Risks to the project will be defined and managed by the business and cost sub-team. Risks will be identified during project analysis, confirmed with primary stakeholders, and continually managed. Risks will be managed by prioritization and recording, creation of

a risk management plan for each significant risk, and ongoing reporting of risks and associated issues. Initial risks are identified below, along with their mitigation approach.
Personnel risk is medium. Student teams will be assigned to each task. This project should be the focus of the student's efforts, which reduces the risk of personnel reassignment. This risk will be reduced by ongoing communication between project sub-teams. Personnel outside the student teams (references, authorities, and contributors) may be reassigned, unavailable, or slow to respond, and thus present a medium risk. This risk will be managed by ongoing communication with outside personnel, as well as communications with stakeholders on the progress of the project, or schedule slips.
Time risk is medium. The project must be completed by September 2007, which strictly limits this resource. If the project grows from the current scope, there may not be sufficient time to complete the project. This risk will be managed by aggressively monitoring the scope of the project, communicating with stakeholders, and managing scheduled activities.
Lack of resources is a low-medium risk. The primary equipment need identified to date is a simulation tool for modeling processes. The use of these tools introduces some risk (availability, speed to learn, suitability), but this will be managed by utilizing simple, accessible, and suitable tools where appropriate. Because this is a student-run (unfunded) project, there is a medium risk of not having suitable simulation tools due to lack of funds. If funds are lacking, no- or low-cost, non-simulation-specific tools will be identified for use.

MILESTONES & DELIVERABLES

Table 20 lists each milestone and Interim Progress Review (IPR) associated with this project. Each milestone will have at least one scheduled meeting with the stakeholders to discuss decisions and deliverables for that milestone. The stakeholders and the JC3M project team must agree that the required deliverable(s) are completed satisfactorily before a milestone is considered complete.

Milestone	***IPR***	***Description***	***Deliverable***	***Date***
1	-	PMP Approval	*Project Management Plan*	16 Feb 2007
2	1	Requirements Approval	*System Requirements Document*	16 Mar 2007
3	2	Alternative Scoring Matrix Approval	*Alternative Matrix*	18 Apr 2007
4	3	Models of Alternatives	*Conceptual Alternative Models & Descriptions*	21 Jun 2007
5	4	Alternative Selection	*Alternative Selection Report*	16 Aug 2007
6	5	Report Delivery & Project Presentation	*Project Presentation and Final Report*	14 Sep 2007

Table 20. List of Milestones and Deliverables.

SCHEDULE

The schedule for the JC3M project team is provided in Figure 47

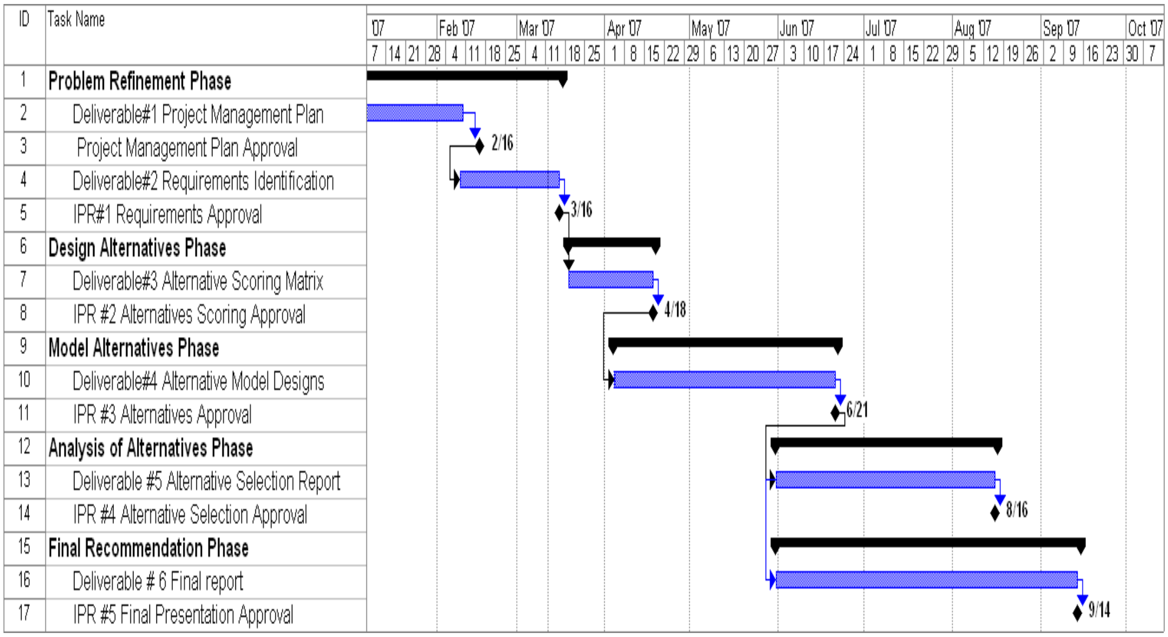

Figure 47. JC3M Project Plan.

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APPENDIX B. NEEDS ANALYSIS QUESTIONNAIRE

After the definition of the primitive need, requirements were captured via stakeholder focused interviews, aided by questionnaires. The multiple responses to the first questionnaire were received with mixed results. All of the responses have not been incorporated due to lack of quality and importance. The questionnaires were reviewed verbally with the stakeholder or provided to them for review electronically; responses from individuals and organizations follow the questionnaire. After reviewing the responses from the first questionnaire the team decided to adapt their approach and generate a second questionnaire with more pertinent questions. JITC's responses from the second questionnaire are provided.

QUESTIONNAIRE VERSION 1.
SYSTEM OF SYSTEM PERFORMANCE ASSESSMENT

As a Systems Engineering project for the Naval Postgraduate School, Monterey, CA, students are creating a system for certifying that a Command, Control, Communications, Computers, and Intelligence (C4I) System of Systems (SoS) can provide stated capabilities. Students are contacting organizations in order to understand current practices, establish a performance baseline, and identify alternative approaches to a solution.

Your organization, which designs, creates, or maintains a complex SoS, has been identified as a candidate to answer this questionnaire and participate in focused interviews, An example SoS would be a commercial passenger aircraft developed as a single system, which incorporates components developed for other aircraft, rather than developing new components. The SoS would be the airframe, avionics, engines, radar, etc. that make up the entire aircraft capability. Your support is requested because it will directly assist the student team, advance the art of Systems Engineering, and increase the efficiency and effectiveness of C4I SoS testing.

1. SoS Definition:

a. What is your SoS?
b. Where is it used?
c. What does it do?
d. What are the high-level components of your SoS?

e. Are components created or managed independently, or are they managed centrally?
f. Was your SoS built to a systems architecture model, as an automobile might be, or did it evolve, as the Internet has?

2. Requirements:

a. Who creates requirements for your SoS?
b. Are requirements generated within or outside your organization?
c. Does the requirements generator have any authority over construction, operation, or maintenance of the SoS?
d. Do requirements for the SoS change over time?
e. Are requirements documented?
f. Can I review your requirements?

3. Validation and Verification (V&V):

a. Is validation ("does it do the right things?") or verification ("does it perform to specifications?") required for your SoS, or for component systems?
b. Who performs V&V for your SoS? Is this an internal or external organization?
c. What are sources of V&V requirements: are they derived from system requirements, user requirements, or other sources?
d. What are the consequences of V&V failure?
e. How is V&V performed for your SoS?
f. If components of the SoS change, is testing performed?
g. Can I view your test procedures and results reports?
h. Is there a process to define:
    i. test environment,
    ii. test criteria,
    iii. test procedures,
    iv. test conduct, and
    v. results reporting?

4. Support:

a. Is your SoS supported by an internal or external organization?
b. How is your SoS maintained?
c. Is maintenance performed by an internal or external organization?
d. Is the SoS subject to change?
e. How is the configuration of the SoS initially recorded, how is it checked, and how is it controlled?
f. If part of the SoS is inoperative, how do users request service?
g. How are users trained on functions of the SoS?
h. Are there user, support, or other training resources I can view?
i. How are support personnel trained?

5. SoS Operations:

a. What is the life cycle of your SoS?
b. Does your SoS operate continuously or intermittently?
c. How long do you expect your SoS to function?
d. Does your SoS have documentation?
e. Can I view the documentation?
f. Is there an alternative or backup to your SoS?
g. What are the consequences (risk of injury or loss of life, risk of damage or loss of equipment, risk of financial loss, other risk) of SoS failure?

6. Your Organization:

a. How long has your organization been in operation?
b. Does your organization follow INCOSE, IEEE, ANSI or other process standards?
c. How long have you operated (sold, created, supported) your SoS?
d. Is there anything you would like to add about your organization or SoS?

MC3T Response to Questionnaire Version 1

1. SoS Definition:

a. What is your SoS? *Marine Corps Systems Command (MARCORSYSCOM) is developing a process to manage the certification of the capability of Command, Control, Communications, Computers, and Intelligence (C4I) Systems of Systems, used by a Marine Air Ground Task Force, to perform their required functions. The process is called MAGTF C4I Capability Certification Test – MC3T.*

b. Where is it used? *MC3T will be a distributed operations, used at Marine Corps Tactical Systems Support Activity (MCTSSA), Camp Pendleton, CA; Marine Corps Systems Command, Quantico, VA; and other sites. MCTSSA performs C4I systems interoperability testing and support, as tasked by the Deputy Commander for C4I Integration (C4I/I) at MARCORSYSCOM.*

c. What does it do? *MC3T will assist in managing the MAGTF C4I SoS as a single system, in terms of enterprise capabilities. With that definition, MC3T will test to ensure the SoS performs to requirements; MC3T will also certify for the Operating Forces that if the SoS is configured in a defined manner, it will meet performance requirements. In the former role, MC3T assists acquisition managers to ensure their systems support SoS level capabilities; in the latter role, MC3T assist the operating forces use the SoS effectively.*

d. What are the high-level components of your SoS? *MC3T functional components consist of requirements definition, capability definition, certification, and documentation.*

e. Are components created or managed independently, or are they managed centrally? *MC3T functional components are managed independently.*

  i. *Marine Corps Combat Development Command (MCCDC) creates doctrine (how components are used) and requirements (what components must do) for the Marine Corps.*

  ii. *MARCORSYSCOM Program Managers acquire components, while a separate MARCORSYSCOM agency (C4I/I) manages SoS integration.*

  iii. *Marine Corps Operational Test and Evaluation Activity (MCOTEA) performs Operational Tests; program managers perform development testing.*

f. Was your SoS built to a systems architecture model, as an automobile might be, or did it evolve, as the Internet has? *The MAGTF C4I SoS has evolved to its current state. MC3T will be built to a systems architecture.*

2. Requirements:

a. Who creates requirements for your SoS?

  i. *MCCDC defines the requirements for systems, but not the SoS;*

  ii. *MARCORSYSCOM Program Managers acquire systems which must meet requirements;*

  iii. *MARCORSYSCOM C4I/I determines C4I integration requirements, and leads MC3T development with MCTSSA support. MCCDC will work with C4I/I and MCTSSA to define enterprise0level requirements.*

  iv. *MCOTEA defines how systems are tested, and conducts or coordinates operational tests only.*

b. Are requirements generated within or outside your organization? *See above.*

c. Does the requirements generator have any authority over construction, operation, or maintenance of the SoS?

  i. *No. MCCDC has no responsibility for the construction, operation, or maintenance of the SoS.*

  ii. *MCOTEA has no responsibility for the construction, operation, or maintenance of the SoS.*

  iii. *MARCORSYSCOM Program Managers have no responsibility for the construction, operation, or maintenance of the SoS.*

  iv. *MARCORSYSCOM C4I/I has no responsibility for the acquisition of the SoS, but is responsible for the integration of the SoS components.*

d. Do requirements for the SoS change over time? *Yes*

e. Are requirements documented? *SoS requirements are documented a component (C4I system) level, but not at the SoS level. One MC3T goal is to define SoS level requirements.*

f. Can I review your requirements? *As requirements are generated they will be made available.*

3. Validation and Verification (V&V):

a. Is validation ("does it do the right things?") or verification ("does it perform to specifications?") required for your SoS, or for component systems?
   - *i. No. The MAGTF C4I SoS exists, and has not been required to have validation or verification performed.*
   - *ii. Components of the SoS that are a Program of Record do have V&V performed, to ensure they meet their system level requirements.*
   - iii. *MARCORSYSCOM C4I/I chartered Federation Of Systems (FEDOS) testing in the past. FEDOS defined a limited C4I SoS, with a controlled configuration of hardware and software.*

b. Who performs V&V for your SoS? Is this an internal or external organization?
   - *MCTSSA conducted FEDOS for MARCORSYSCOM C4I/I.*
   - *MCTSSA will conduct MC3T testing for MARCORSYSCOM C4I/I.*

c. What are sources of V&V requirements: are they derived from system requirements, user requirements, or other sources?
   - *For the conduct of FEDOS and predecessor tests, MCTSSA conducted a search for SoS V&V requirements. There are no formal SoS-level requirements at all. Where available, V&V requirements were determined, in descending preference, from:*
     - *Integrated Architecture Data Stores*
     - *Doctrine*
     - *Training and Readiness Manuals*
     - *Schoolhouse Documents*
     - *System Manuals & Help Files*
     - *Unit-level Standard Operating Procedures (SOP)*
     - *Subject-matter Experts*
     - *Best guess synthesis*

d. What are the consequences of V&V failure?
   - *Prior to MC3T, failure of V&V, for a system in acquisition or sustainment, was communicated to the "owning" PM. Because SoS level V&V was not a requirement, the PM could ignore the failure, address the failure with a risk mitigation strategy, or rebuild/refine the system.*
   - *The consequences of failure of MC3T, i.e. failing to demonstrate the defined capability, are not defined.*

e. How is V&V performed for your SoS? *MC3T is developing the capability certification testing process.*

f. If components of the SoS change, is testing performed? *MC3T will incorporate capability testing for new or modified components of the MAGTF C4I SoS.*

g. Can I view your test procedures and results reports? *MC3T will conduct the first test event in October 2007. Procedures will be made available for review as they are developed. Test methodology documents are more important.*

h. Is there a process to define:

i. test environment,

ii. test criteria,

iii. test procedures,

iv. test conduct, and

v. results reporting? MC3T will conduct the first test event in October 2007. Definitions, procedures, and criteria will be made available for review as they are developed.

4. Support:

a. Is your SoS supported by an internal or external organization? The MAGTF C4I SoS is supported by:

- *MCTSSA Operating Forces Tactical Systems Support Center (OFTSSC) provides 24x7 remote support for tactical C4I systems to the Marine Corps and other Operating Forces.*
- *Marine Corps Network Operations and Security Command (MCNOSC) provides network defense and technical support.*
- *Marine Corps Operating Forces operate tactical C4I systems around the world.*
- *MARCORSYSCOM Program Managers provide varied levels of support for their systems.*

b. How is your SoS maintained? *By the Operating Forces, MCNOSC, and MARCORSYSCOM.*

c. Is maintenance performed by an internal or external organization? *Maintenance is performed by MCNOSC and the Operating Forces; both are external to MCTSSA.*

d. Is the SoS subject to change? *Frequently.*

e. How is the configuration of the SoS initially recorded, how is it checked, and how is it controlled? This may be an operational question, and requires vetting. See Annex K to the Oplan.

f. If part of the SoS is inoperative, how do users request service? *Direct contact with MCNOSC or Operating Forces Tactical Systems Support Center.*

g. How are users trained on functions of the SoS? *Users may receive training on component systems. There is no SoS level training.*

h. Are there user, support, or other training resources I can view? *Resources can be made available on a case-by-case basis.*

i. How are support personnel trained? *SoS support personnel at the OFTSSC are component (system-level) experts, with formal training on a system. They are cross trained on other systems over time.*

5. SoS Operations:

a. What is the life cycle of your SoS?
   - *Once the MAGTF C4I SoS is established, it remains operational until a) the MAGTF is disbanded and returns to garrison, or b) the Marine Corps operation (Combat, Humanitarian Assistance, Training Exercise) is completed.*
   - *MC3T is being defined, with the first demonstration of a test event in October 2007.*

b. Does your SoS operate continuously or intermittently?
   - *The MAGTF C4I SoS operates as described above.*
   - *MC3T is not an SoS, but will operate on a continuous basis, conducting assessments as needed.*

c. How long do you expect your SoS to function? *For the foreseeable future.*

d. Does your SoS have documentation? *MC3T Is not an SoS, but documentation is being developed.*

e. Can I view the documentation? *As it is developed.*

f. Is there an alternative or backup to your SoS? *The current ad-hoc system is the alternative.*

g. What are the consequences (risk of injury or loss of life, risk of damage or loss of equipment, risk of financial loss, other risk) of SoS failure?
   - *If MC3T works, it will reduce systems development, integration, and support costs; the current ad-hoc system costs more in all these areas.*
   - *MC3T will also increase the effectiveness and efficiency of the MAGTF C4I SoS; users will be more effective at managing and using information. If MC3T fails, users will be forced to operate in their current ad-hoc fashion.*

6. Your Organization:

a. How long has your organization been in operation? *MCTSSA has been in operation since the 1970s.*

b. Does your organization follow INCOSE, IEEE, ANSI or other process standards? *MCTSSA does not have a defined, repeatable set of process standards. MC3T is an attempt to introduce process standards.*

c. How long have you operated (sold, created, supported) your SoS? Since ______

d. Is there anything you would like to add about your organization or SoS?

JTEM CTM Response to Questionnaire Version 1

1. SoS Definition:

a. What is your SoS? *A Joint SoS test process.*

b. Where is it used? *JTEM will work with Live, Virtual, and Constructive elements on joint distributed environment ranges.*

c. What does it do? *JTEM will define a Joint SoS test process. .*

d. What are the high-level components of your SoS? *DOTMLPF*

e. Are components created or managed independently, or are they managed centrally? *JTEM will be created centrally (DOT&E), with inputs from the JTEM COI. As the JTEM process becomes included in JCIDS and other acquisition processes, it will be managed and executed independently.*

f. Was your SoS built to a systems architecture model, as an automobile might be, or did it evolve, as the Internet has? *JTEM will be built to a systems architecture.*

2. Requirements:

a. Who creates requirements for your SoS? *JTEM is creating SoS testing requirements, based on COI input. Note the JTEM charter, the transformation roadmap. At Rock Drills a gap was discovered in requirements for Joint mission test requirements.*

b. Are requirements generated within or outside your organization? *JTEM requirements are generated internally, other than those requirements that come from DOD acquisition instructions (JCIDS, others).*

c. Does the requirements generator have any authority over construction, operation, or maintenance of the SoS? *JTEM does not have any authority over construction, operation, or maintenance of the SoS, first, because JTEM is a limited-duration project, and second, because JTEM will define a process for use by others.*

d. Do requirements for the SoS change over time? *As the JTEM COI matures, and JTEM events are assesses, SoS (JTEM) requirements change.*

e. Are requirements documented? J*TEM is defining requirements as they are identified.*

f. Can I review your requirements? *Yes, see latest documentation (Draft) Rock Drill Event Final Report.*

3. Validation and Verification (V&V):

a. Is validation ("does it do the right things?") or verification ("does it perform to specifications?") required for your SoS, or for component systems? *JTEM has conducted V&V through rock drills (tabletop exercises) to determine if recommended processes, at their current state, work. Rock drills also expose gaps and seams between current processes.*

b. Who performs V&V for your SoS? Is this an internal or external organization? *V&V (rock drills) was conducted internally, with participants from almost all services and many agencies.*
c. What are sources of V&V requirements: are they derived from system requirements, user requirements, or other sources? *System requirements, doctrine, regulations, and user requirements.*
d. What are the consequences of V&V failure? *"Failure" of V&V, in the early stages of JTEM maturation, is very unlikely, because JTEM is identifying requirements, testing iteratively, and exposing gaps and seams in models and processes. If a current version of JTEM was to fail, it would provide more information for analysis, and be the precursor to updated models and processes.*
e. How is V&V performed for your SoS? *See (Draft) Rock Drill Event Final Report for detail.*
f. If components of the SoS change, is testing performed? *Yes. .*
g. Can I view your test procedures and results reports? *See (Draft) Rock Drill Event Final Report for detail. .*
h. Is there a process to define:
   a. test environment,
   b. test criteria,
   c. test procedures,
   d. test conduct, and
   e. results reporting?

   There will be a series of test events (USAF?) this year, and a follow-on next year with FCS [Future Combat System].

4. Support:

a. Is your SoS supported by an internal or external organization? *JTEM is supported internally. On execution/implementation, JTEM will be supported by using organizations, which may utilize internal or external resources.*
b. How is your SoS maintained? *On execution/implementation, JTEM will be supported by using organizations, which may utilize internal or external resources.*
c. Is maintenance performed by an internal or external organization? *On execution/implementation, JTEM will be supported by using organizations, which may utilize internal or external resources.*
d. Is the SoS subject to change? *JTEM is evolving and expects to continue to evolve.*
e. How is the configuration of the SoS initially recorded, how is it checked, and how is it controlled? *JTEM will change as the System Under Test (SUT) changes. User organizations will control configuration through current and future internal processes.*

f. If part of the SoS is inoperative, how do users request service? *On execution/implementation, JTEM will be supported by using organizations, which may utilize internal or external resources.*
g. How are users trained on functions of the SoS? *On execution/implementation, JTEM will be supported by using organizations, which may [generate?] current or future processes for user training.*
h. Are there user, support, or other training resources I can view? *There may be access to limited training information on the conduct of rock drills.*
i. How are support personnel trained? *On execution/implementation, JTEM will be supported by using organizations, which may [generate?] current or future processes for user training.*

5. SoS Operations:
a. What is the life cycle of your SoS? *JTEM, by charter, will only last until [2009?]. After this point, JTEM will be supported by using organizations.*
b. Does your SoS operate continuously or intermittently? *TheJTEM process will operate continuously as SoS are under test. .*
c. How long do you expect your SoS to function? *JTEM is ivolving and expects to continue to evolve.*
d. Does your SoS have documentation? *See (Draft) Rock Drill Event Final Report for detail. See also other JTEM documents.*
e. Can I view the documentation? *See (Draft) Rock Drill Event Final Report for detail. See also other JTEM documents.*
f. Is there an alternative or backup to your SoS? *Current disparate, fragmented, and ad hoc testing.*
g. What are the consequences (risk of injury or loss of life, risk of damage or loss of equipment, risk of financial loss, other risk) of SoS failure? *Higher resource use (cost) for testing due to "reinvention" of test processes for events; lower confidence in capability of SoS to achieve capability; increased possibility of Invalid assessment of SoS suitability for use (milestone decisions).*

6. Your Organization:
a. How long has your organization been in operation? *JTEM was chartered in 2006.*
b. Does your organization follow INCOSE, IEEE, ANSI or other process standards? ________.
c. How long have you operated (sold, created, supported) your SoS? *JTEM was chartered in 2006*
d. Is there anything you would like to add about your organization or SoS?

QUESTIONNAIRE VERSION 2.

JITC Response to Questionnaire Version 2

1. SoS Assessment Planning

a. Does planning for an assessment have a relationship to the scope of the assessment? *Yes. For larger, more complex systems, or systems requiring multiple test venues we develop an ICEP (Interoperability Certification Evaluation Plan -- basically, a plan for managing the testing). Interoperability Test Plans (ITPs) provide detailed plans/procedures for individual tests. Larger programs will also have a TEMP or similar document. For many, if not most assessments, JITC leverages off testing conducted by others, including use of other's test plans/procedures. Usually, this involves reviewing OT [Operational Test] plans to ensure adequate data is collected for JITC to perform an interoperability evaluation.*

b. Does your organization have a planning template for assessments? *Not sure what is meant. We have guidance/policy, there is also guidance/policy in CJCSI 6212.01, etc.*

c. Does your organization use plans or results of previous assessments to aid in planning for new events? *Absolutely!*

2. SoS Assessment Resources:

a. How are resources required to conduct the assessment (time, people, hardware, software, processes) identified? *During planning.*

b. How are resource gaps identified and mediated? *Same.*

c. How are resource conflicts identified and mediated? *Same. Conflicts with external resources (e.g., availability of interfacing systems) can be raised to the MCEB[Military Communications & Electronics Board /Interoperability Test Panel or Joint Staff (J-6), if necessary, but this is rarely required.*

d. How are priorities of support established: *This was covered in previous versions of 6212, however, it never really became an issue by itself. See excerpt from CJCSI 6212.01C below:*

"DISA[Defense Informatin Systems Agency] (JITC) uses the following organizational prioritization for testing, assessing, and certifying interoperability: (i) joint IT and NSS [National Security Systems] systems that support the unified commands, (ii) joint IT and NSS systems that are acquired by the Services, and (iii) systems that are acquired by the Defense agencies.

The order for functional prioritization is: (i) strategic warning and communication systems that support the unified commands, the Secretary of Defense, and the Commander-in-Chief; (ii) tactical systems that support *the unified commands; (iii) C2 systems that support the unified commands; and (iv) Combat service support systems that support the unified commands."*

(For some testing at JITC, such as standards conformance and DSN [Defense Switched Network], there is a simple FIFO {First In, First Out] queue approach.

i. External agency priorities?
ii. Higher Head Quaters priorities?
iii. Other?

3. SoS Components Evaluated

a. How are components of the SoS identified for participation in the assessment? DoD 4630 and 5000 series, CJCSI 6212.01, etc. require systems to be interoperable, have requirements certified, and receive JITC Joint Interoperability Test Certification. Every system/system component (even legacy, unless granted a waiver) is in effect "nominated" by birth in the DoD community. J-6I certified capabilities documents identify systems/system components (e.g., in SV [Systems View]-1/2 architecture products).
b. What organization(s) nominate components for assessment? *The PM/sponsor is responsible for ensuring that interfacing systems participate in testing (see 6212).*
c. How are conflicts resolved? *MCEB/ITP, J-6I.*

4. SoS Performance Requirements

a. How are SoS performance requirements identified? *Integrated architecture products and associated information (e.g., an interface may have an interface control document). Ideally, architecture information from interfacing systems would be used to validate requirements for a system. There are also overarching requirements such as the NCOW[Net-Centric Operations Warfare- Reference Model] RM (including DoD Data Strategy), GIG ICD, GIG Architecture, etc.*
b. What organization(s) identify SoS performance requirements?
   iv. Subject Matter Experts?
   v. Test Agency?
   vi. Program Office?
   vii. End user community?
   viii. Doctrine organizations?
   ix. Joint or Service organizations?
   x. Other? *All of the above, to some extent. PMs/sponsors (e.g., in the Army the combat developers generate initial requirements) create requirements that are reviewed by the JS, users, COCOMs, DISA, JITC, and other organizations.*
c. When are performance requirements identified:

xi. Before assessment request is accepted?
xii. After approval of assessment?
xiii. Before assessment planning stage starts?
xiv. Other? *6212 requires that requirements be testable and measurable from the start, and that test planning start early in the life-cycle. However, sometimes requirements are not finalized/certified as early as desirable, and sometimes requirements are not as testable & measurable as they should be.*

d. How are conflicting requirements recorded and resolved? *Conflicts should be resolved during the document development and review process. If conflicts are identified later, J-6I may be engaged to resolve conflicts.*

5. SoS Performance Criteria

a. When are SoS performance criteria (i.e. speed, accuracy, timeliness, authenticity, repeatability…) identified? *When the requirements are developed, although, as noted above, sometimes this information must be derived from supporting documents. (Integrated architecture products include timeliness, etc.)*

b. If performance criteria are not identified before an evaluation of the SoS is requested, what happens? *JITC can evaluate a system based on draft requirements, and produce an interoperability assessment. After the requirements are certified the assessment letter could be upgraded to a certification, provided the system passes and there are no changes to the requirements that would require additional data not collected during previous testing. Requirements that are not critical, may be addressed by a status of "not tested," if other data still supports an assessment of critical items. (Threshold KPP requires only joint critical requirements to be met.)*

c. How are conflicting requirements resolved? *See above.*

6. SoS Threshold and Objective values.

a. How are threshold and objective values (i.e. 500 KPH threshold, 700 KPH objective; 10 meter Circular Error Probable (CEP) threshold, 5 meter CEP objective; less than 10 seconds threshold…) identified? *NR-KPP has threshold/objective values, as do KIPs and other requirements.*

b. Who participates in this identification? *Same as for requirements.*

c. How are conflicting requirements resolved? *Ditto.*

7. SoS Test Script

a. What organization creates the test script? *Usually, the primary test organization (e.g., OTA[Operational Test Agency]); JITC reviews test plans, procedures, scripts, etc. to ensure data collected is adequate to address interoperability evaluation.*

b. What stakeholders approve the test script? *Generally, the testing organizations and others involved in the various working groups (varies by type, size of system).*

c. How are conflicts resolved? *By test working groups. Interoperability issues can always be raised to the MCEB/ITP or J-6, although that would be less likely for issues involving very technical details of a script.*

8. SoS Configuration:

a. When is the SoS assessment configuration defined? *JITC tests to the approved Information Assurance (IA) configuration. The configuration must represent a realistic operational environment.*

b. When is the SoS assessment configuration installed? *During pre-test activities.*

c. Who can authorize changes to the SoS assessment configuration, and under what conditions? *The approved IA configuration must be used. Any deviations would have to be reported as testing limitations, including an assessment of the impact they may have on interpretation of results. If changes are necessary to proceed with testing (e.g., there are showstoppers that would make continued testing a waste), the impact on previously collected data must be assessed and regression testing performed as needed to revalidate earlier results.*

9. What are milestones in the planning, conduct, and reporting of an assessment:

a. Planning?

b. Conduct?

c. Reporting?

d. Other? *JITC uses a basic 4-step process. Requirements (identify requirements, ensure they are J-6 certified, testable/measurable, etc.); plans (ICEP, ITPs, [Interoperability Certification Evaluation Plan, Interoperability Test Plan] etc.); conduct (more often monitoring other's testing and collecting data); reporting (detailed test reports, assessments, certifications, etc.). JITC, per DoDI 4630.8, also provides input to the OTRR [Operational Test Readiness Review]. Standards conformance or other assessments may also enter into the overall testing program at various stages.*

10. Conduct of Performance Assessment

a. Who executes the test script:

   i. Contractors?

   ii. government civilians?

   iii. other? *A realistic environment usually requires that the typical user performs the operations. Typical users may be military, civilians, contractors, etc. Some types of systems/situations may* *require supplementing the typical user with other types of personnel, as long as this does not invalidate test results.*

b. Who supervises the conduct of the assessment:
   iv. Test Agency personnel?
   v. Program Office personnel?
   vi. Combination/Other? *Lead test organization, usually OTA. JITC "supervises" (or monitors) testing as need to ensure interoperability data is adequate.*

11. Assessment Results

a. Who records assessment results:
   i. Test Agency personnel?
   ii. Program Office personnel?
   iii. Combination/Other? *Same as supervising, although "operators" record some data – data collection is automated to the extent practicable.*

b. How are results expressed?
   i. Accurate until SoS components change? *Joint interoperability Test Certificates state "This certification expires upon changes that affect interoperability, but no later than three years from the date of this memorandum." Changes that affect interoperability could include any or all of the following: hardware and/or software changes to the system, DOTMLPF changes to the system, or similar changes to interfacing systems.*
   ii. Accurate for a period of time? *Three (3) years, because most systems have minor updates (sometimes frequently) and, even if the system under test does not change, interfacing systems are likely to have changed, or requirements may have (should have) changed, etc.*
   iii. Other?

c. How are results expressed:
   i. Pass/Fail? *Yes*
   ii. Numerically scored? *Yes*
   iii. Narrative description (without score)? *Yes*
   iv. Other? *JITC reports an overall status (e.g., threshold NR-KPP met); an overall status of the elements of the NR-KPP (net-centric, information exchange, KIP, IA, and DISR [DoD IT Standards Registry]compliance); status of interfaces (certified, not certified, not tested), and more detailed status on net-centric requirements (enterprise (NCES [Net-Centric enterprise Services]/COI)-level services/data), information/data exchanges (OV [Operational View]-3/SV-6), KIP and DISR [DoD IT Standards Registry] compliance, and IA related compliance. Depending on the size/complexity of requirements, some more detail may be provided in the certification letter (consisting of a memo and summary*

sections), or in a detailed test report if too voluminous to include in the certification letter. JITC reports the degree to which requirements are met (e.g., all critical requirement met, all requirements met) and the expected operational impact (none, minor, moderate, major, or critical) of any discrepancies.

12. Communications:

a. How frequently are results reported *Varies with size/complexity, length of testing, visibility of program, etc. Quick Look reports/briefings are sometimes produced, informal testing status can be produced daily, etc. Detailed test reports are produced after testing (sometimes by organizations other than JITC); certification letters are finalized and distributed after results have been analyzed.*
   - xv. Under predefined conditions?
   - xvi. On demand?
   - xvii. Daily/weekly?
   - xviii. At the conclusion of the assessment?

b. Is there a separate assessment report? *For large/complex systems, yes.*

c. Who controls distribution of the assessment results?
Distribution of JITC interoperability certifications is specified in 6212. Test reports produced by JITC are provided to the sponsor and other interested/authorized parties.

13. Organization Performance Evaluation Metrics:

a. Do you measure equipment resources used per event?
If equipment is provided/controlled by JITC, use is monitored to some extent. Resources that are periodically used to support testing (part of an existing lab or general test capability) are not necessarily tracked by each individual test event (and some resources may be shared by more than one system during a test event). An example is NIPRNET [Non-Secure Internet Protocol Router Network] access. It also depends on the nature of the testing, overall test configuration (many involve distributed test resources provided by a number of organizations), etc.

b. Personnel labor hours used per event? *Yes.*

c. Duration of processes and entire event? *Yes.*

d. Other resources used in planning, conducting, and reporting an event?
Much of the interoperability testing is piggybacked on testing performed mostly by others, usually OT organizations. JITC tracks resources used for its portion of planning, conduct, and reporting.

14. SoS Performance Metrics:

a. Does your organization evaluate the performance of the SoS after testing?
Whenever possible, JITC continues to observe performance by participation in numerous exercises, other interoperability testing that includes previously tested systems as participants, reports from the field

(from various sources), etc. When necessary, JITC reviews the previously determined interoperability status to determine if the status has changed, possibly requiring additional testing and updating any previous certification letters. Systems with known discrepancies, including failure to obtain an interoperability certification, may be reported to J-6I and/or the MCEB/ITP for additional action (there is a J-6I delinquency program/ITP watch list). JITC/J-6I also track expiring certifications; MCEB /ITP tracks ICTOs [Interim Certification to Operate] (part of qualifying for an ICTO is a plan for obtaining JITC certification, usually within a year).

b. Does your organization record comments or queries from end users? *After fielding, JITC has a 24/7 Hotline to address inquiries/issues from end users (and anyone else, for that matter). Appropriate action is taken, including deploying personnel to help resolve interoperability problems. (During testing, see below.)*

c. Does your organization provide feedback to program developers on end user comments? *JITC does not normally collect end user comments after a system is fielded, however, appropriate organizations are notified of serious interoperability issues as they are identified. (See above.) User comments during testing are normally recorded and provided to the sponsor as part of the SOP for most testing. When there are discrepancies during testing, JITC provides an "expected operational impact" based on input from the user community.*

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APPENDIX C. QUALITY OF PLANNING OUTPUTS QUESTIONNAIRE

This appendix consists of three sections. First, a description of the research that went into the methodology behind the Quality of Planning Outputs Questionnaire is provided. Second, the actual Quality of Planning Outputs Questionnaire is provided. Third, tables of the results are provided, including a table with final calculation of the raw scores.

EVALUATION MEASURE: QUALITY OF PLANNING OUTPUTS

The team considered two scales to process SME questionnaire responses.

Osgood's semantic differential scale [Pershing, 2000:1-7] measures subjective feelings indirectly by comparing extremes of the scale using words of opposite meaning. Respondents consider a list of paired opposite adjectives on a continuum of 5 to 11 points and recorded their feelings, likes, perceptions on the scale. The scale produces interval data that can be used in statistical analysis. Concise directions, which are understood by all respondents in the same way, are mandatory for effective use. The varied background of the respondents was valuable for their experience, but made this scale less effective for this questionnaire.

A Likert [Mitchell and Jolley, 2001: 485-487] scale is useful because responses can be summed to provide an overall score from each respondent. Statistical analysis, typically a t-test, can be used to determine the validity and accuracy of the responses. Likert scales are often constructed of two positive responses, two negative responses, and a neutral response. The team constructed a scale of two positive responses and two negative responses, and values from 1 (worst) to 4 (best), in order to avoid any undecided or "fence sitter" answers.

Determining the Score for the Evaluation Measure Quality of Planning Outputs

The team created a questionnaire consisting of four questions that covered key areas of what constitutes the quality of planning outputs. Each question also contained a criterion in order to help respondents differentiate between a value of 1 to a value of 4.

The team administered the questionnaire to one SME from MCTSSA and two SMEs from NAWC China Lake. Responses are recorded in Table 21, Table 22, and Table 23. The Table 22 response is skewed with respect to the responses in Table 21 and Table 23. The Table 22 respondent indicated the FCB and SCR alternatives were not as clearly understood, and their ability to produce quality planning products appeared to be reduced.

The raw score was calculated by summing the scores for each alternative from the respondents. The overall score for the evaluation measure was calculated by dividing the raw score by the number of questions, which were four. The equation for *overall score* is

overall score = raw score / # questions. (5)

In order to use this score with the weights utilized in AoA, the raw index was calculated by dividing the overall score by the number of respondents. Thus, a raw index will contain a value from 1 to 4. The equation for raw index is

raw index = overall score / # SMEs. (6)

The raw index was used in AoA to compare quality of planning outputs for each alternative.

Participants

- The SME respondent from MCTSSA was Mr. Scot Hoesly; the SME respondents from NAWC China Lake were Mr. Stephan Bussell and Mr. Robert Mount.

EVALUATION MEASURE: QUALITY OF PLANNING OUTPUTS QUESTIONNAIRE

Question #1: Ability to Create Planning Documents - Does the alternative develop planning products (test plans, test procedures) for C4I SoS evaluations?

Objective: Planning products are produced each time the process is executed.

Criteria:

Criterion	Score
The alternative always produces planning products for evaluating C4I SoS.	4
The alternative often produces planning products for evaluating C4I SoS.	3
The alternative sometimes produces planning products for evaluating C4I SoS.	2
The alternative never produces planning products for evaluating C4I SoS.	1

Question #2: Quality of Planning Documents – Does the alternative deliver planning documents that conform to standards established by relevant official directives and guidance? (See examples of standards below)

Objective: The planning products conform to standards.

Criteria:

Criterion	Score
The alternative produces planning documents that conform to standards established by all Services affected by the SoS	4
The alternative produces planning documents that conform to the majority of standards in directives	3
The alternative produces planning documents that conform to standards in a single Service's directives	2
Planning documents do not conform to established standards	1

Question #3: Usability of Planning Documents – Does the alternative produce planning products that can be used for C4I SoS evaluations?

Objective: The planning products can be used easily in an organization tasked with designing and executing SoS evaluation.

Criteria:

Criterion	Score
The alternative provides planning products that are completely usable for executing C4I SoS evaluations	4
The alternative provides planning products that are usable for executing C4I SoS evaluations	3
The alternative provides planning products that are somewhat usable for executing C4I SoS evaluations	2
The alternative provides planning products that are not usable for executing C4I SoS evaluations	1

Question #4: Planning Documents determination of Capability - Does the alternative produce outputs that measure C4I SoS capabilities?

Objective: The planning products are effective for evaluating C4I SoS capabilities.

Criteria:

Criterion	Score
Planning documents ensure execution of the evaluation will measure all desired capabilities of the SoS	4
Planning documents ensure evaluation of most of the desired capabilities of the SoS	3
Planning documents ensure evaluation of some of the desired capabilities of the SoS	2
Planning documents ensure evaluation of basic data exchange and technical interfaces of the SoS	1

QUESTIONNAIRE RESULTS.

Table 21, Table 22, and Table 23 display the results from the questionnaires for each of the SMEs. Table 24 provides the raw index which was used during the AoA in determining the quality of planning outputs for each alternative.

Alternative	**Question 1**	**Question 2**	**Question 3**	**Question 4**	**Score**
FEDOS	3	3	4	2	**12**
MC3T	3	2	3	3	**11**
JTEM CTM	3	3	4	3	**13**
SCR	4	4	3	3	**14**
FCB	4	3	4	4	**15**

Table 21. Scot Hoesly's Responses to Quality of Planning Outputs Questionnaire.

Alternative	**Question 1**	**Question 2**	**Question 3**	**Question 4**	**Score**
FEDOS	4	4	4	4	**16**
MC3T	4	4	4	4	**16**
JTEM CTM	4	4	4	4	**16**
SCR	2	2	2	2	**8**
FCB	1	1	1	1	**4**

Table 22. Stephan Bussell's Responses to Quality of Planning Outputs Questionnaire.

Alternative	**Question 1**	**Question 2**	**Question 3**	**Question 4**	**Score**
FEDOS	4	3	2	1	**10**
MC3T	4	3	3	2	**12**
JTEM CTM	4	3	3	2	**12**
SCR	4	3	3	4	**14**
FCB	4	3	3	4	**14**

Table 23. Robert Mount's Responses to Quality of Planning Outputs Questionnaire

Alternatives	**Raw Score**	**Raw Index**
FEDOS	38	3.167
MC3T	39	3.250
JTEM CTM	41	3.417
SCR	36	3.000
FCB	33	2.750

Table 24. Table of Raw Index Scores.

APPENDIX D. DESIGN ALTERNATIVES DETAILS

This Appendix discusses alternatives generation and feasibility screening of the Design Alternatives phase in further detail. This Appendix begins with detailed descriptions of the alternatives generated during the alternatives generation phase, and is concluded with a detailed description of the feasibility screening process that was used to select feasible alternatives for the JC3M project.

GENERATED ALTERNATIVES

Exhaustive Alternative

The "Exhaustive" approach embodied the theme of doing everything, without limiting the evaluation to specific capabilities, or user-directed systems or functions. This approach would evaluate every component of the SoS, every function, every system under test, every capability, and every component of the individual systems. The theory was that by exhaustive testing, data would be generated for every evaluation measure, and a complete evaluation of the SoS would be provided.

User Defines Alternative

The "User Defines" approach was based on the user/stakeholder determining the functions, capabilities, and components of the SoS under evaluation. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities requested by the user. The theory was that by selective testing, the time required to plan an evaluation would decrease, the user would get a selected review of capabilities and functionality, and performance measures would accurately reflect the capabilities under review.

"Do No Harm" Alternative

The "Do No Harm" approach was based on the use of JITC to determine the capabilities, functions and components of the SoS under evaluation. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities identified by JITC, in their current processes, as required to demonstrate interoperability. The theory was that by selective testing, investigation of and consultation on performance measures would be reduced, saving time in planning an evaluation. The user would get a selected review of capabilities and functionality which would be directly related to interoperability evaluations.

System Anomaly Report (SAR) Alternative

The "System Anomaly Report (SAR)" approach was based on determining the functions, capabilities, and components of the SoS under evaluation by reference to anomalies or concerns received from the user community. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities identified by the user community, and recorded in SARs, as problems in previous increments of the SoS. The theory was that the user community would define unacceptable performance of the SoS, and threshold values could thus be deduced. This would enable selective testing, so that investigation of and consultation on performance measures would be reduced, saving time in planning an evaluation. End users would get a selected review of capabilities and functionality focused on reported issues, and performance measures would accurately evaluate the capabilities, functions, and components of interest.

Deliberate Method Alternative

The "Deliberate Method" approach was based on the most effective process to determine the functions, capabilities, and components of the SoS under evaluation. This approach would exhaustively identify those components of the SoS, systems under test, component systems, and capabilities which are affected or are under review. The theory was that by using the best systems engineering approach to define the most discriminating testing, the evaluation would be more effective in measuring the performance of the SoS, systems under test, or capabilities, and the stakeholders would derive greater benefit from focused testing. This approach was also created in an attempt to define the highest performance alternative, in order to offer a markedly different alternative solution to compare to other alternatives.

Capabilities Documentation Alternative

The “Capabilities Documentation” approach was based on the use of requirements documents to determine the functions, capabilities, and components of the SoS under evaluation. This approach would evaluate components of the SoS, systems under test, component systems, and capabilities that have performance measures defined by Joint Capabilities Integration and Development System (JCIDS) documentation, such as an Initial Capabilities Document, Capability Development Document, or Capability Production Document. The theory was that by reviewing JCIDS documentation, investigation of and consultation on performance measures would be reduced, saving time in planning an evaluation; the SoS would be evaluated in accordance with its documented intended purposes; and performance measures would accurately reflect the capabilities of the SoS.

Program Manager Direction Alternative

The “Program Manager Direction” approach was based on the acquisition Program Manager, responsible for the SoS or system, determining the functions, capabilities, and components of the SoS under evaluation. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities requested by the PM. The theory was that the Program Manager would define threshold values, and that by selective testing, investigation of and consultation on performance measures would be eliminated, saving time in planning an evaluation. The PM, as representative of the acquisition and user community, would get a selected review of capabilities and functionality, and performance measures would accurately evaluate the issues in question.

Test Agency Direction Alternative

The “Test Agency Direction” approach was based on the test agency determining the functions, capabilities, and components of the SoS under evaluation. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities, as determined by the test agency, to bear on the issues under investigation. The theory was that the test agency was an objective evaluator of both performance measures and SoS performance, and would provide an unbiased, accurate, and methodical evaluation of the SoS. Further, time could be saved in planning an evaluation by reducing the need for outside consultation. This assumed the test agency would be more efficient in establishing test requirements than other organizations. This approach was also created in an attempt to offer a markedly different alternative solution to compare to other alternatives.

Change Driven Alternative

The "Change Driven" approach was based on the test agency or stakeholder determining what is different in the SoS configuration or employment, in order to determine the functions, capabilities, and components or functions of the SoS to be evaluated. This approach would evaluate only those components of the SoS, systems under test, component systems, and capabilities which have changed, in order to document performance variances. The theory was that by testing only changed items, time would be saved in planning an evaluation. The user would get a review of capabilities and functionality that are different as a result of and attributed to changes to the SoS. Further, performance measures would accurately reflect the capabilities under review.

FEASIBILITY SCREENING

After reviewing the nine alternatives from the standpoint of feasibility and similarity, the "User Defines" alternative was eliminated from further consideration because it was very similar to the "Program Manager Defines."

The "Do No Harm" alternative was eliminated because the team planned to consider the performance of baseline processes from other organizations (JTEM, MC3T, MCTSSA) from the start, and a primary goal of this alternative generation process was to consider two entirely new alternatives, rather than exclusively baseline processes.

The Capabilities Documentation alternative was eliminated because it was similar to the SAR alternative in that both alternatives rely on outside documentation for identification of threshold values.

The revised list of alternatives was left as Ad-Hoc, SAR, Deliberate Method, Program Manager Direction, and Change Driven.

One process of screening alternatives with multiple criteria [Blanchard and Fabrycky, 1998: 567] is to assign weighting factors to each evaluation measure, score performance on each evaluation measure, and sum scores for each alternative, which results in an overall scores. This method was not used because all five alternatives under consideration were theoretical, and there was no measurable data to compare. Simulation or modeling of the alternative was not employed, because the goal at this stage was not to compare the performance of alternatives, but to reduce the field to two alternatives.

Another method of screening alternatives [Thuesen and Fabrycky, 2001: 567] is to perform paired comparisons. Paired comparisons contrast the performance of any two alternatives to each other on a single MOE, to determine which alternative is superior. Alternative A is compared to B, on a single parameter, with the result a ranking of the two alternatives: A > B. The process is repeated (B>C, C>D, D>E…) for each alternative and MOE. The property of transitivity (if A > B and B > C, then A > C) is applied to the results and a ranking of all alternatives can be generated. Paired comparison was not used to screen the alternatives because the comparison of alternatives is subjective, depends on expert evaluation of the alternatives, and as with weighting factors, there was no measurable data to compare. Simulation and modeling of the alternative's performance was not employed, as stated above, because the goal was to reduce the field of alternatives.

Systematic elimination [Thuesen and Fabrycky, 2001: 569] also supports the evaluation of the alternatives on each parameter, by eliminating alternatives that do not meet a minimum level of acceptability. Systematic elimination can be implemented in a restrictive manner by stipulating that if an alternative achieved a passing score on each criterion, the alternative would be retained for further development. An unrestrictive implementation of systematic elimination would keep any alternative that achieved a passing score on at least one criterion. A moderate approach would keep alternatives that meet more, or fail fewer, criteria. This process was also rejected because it depends on performance scores, which do not exist for four of the five alternatives.

In cases where performance data are not known, a datum design comparison [Cross, 2000:156] can be conducted. In this process, each alternative is compared, parameter by parameter, against a known quality solution. The result of each comparison is recorded as the same (=) performance, better than (+), or worse than (-) the baseline. At the completion of the comparisons the positive rankings for each alternative are summed, as are the negative rankings, and an overall total is calculated for each alternative. In this manner the qualitative comparisons of performance against the baseline were converted into a quantitative ranking of alternatives. The overall totals were used to screen out the untenable alternatives from further consideration.

In the case of the five remaining alternatives, the datum design comparison was used, and the parameters for scoring were drawn from the evaluation measures that support the JC3M functional hierarchy. The advantage of using the datum design comparison is that the team understands the strengths and weaknesses of the baseline alternative. Thus, by comparing the proposed new alternatives with the evaluation measures against the baseline the team could speculate whether it will be better, worse, or the same as the baseline for each of these evaluation measures. Also, these evaluation measures were used for comparing the final five alternatives in the AoA.

For each evaluation measure, each alternative was scored against the MCTSSA (FEDOS) baseline datum. The scoring criteria were as follows: (+) the alternative was expected to perform better than the baseline, (-) the alternative was expected to perform worse than the baseline, and (=) the alternative was expected to perform the same as the baseline. The team reviewed the known performance of the baseline against the projected performance of the alternative process, function by function. This ranking was performed initially without the aid of an SME. After evaluating each alternative, the (+) values were summed and the (-) values were subtracted, to calculate a final score. Deliberate Method and Change Driven alternatives were ranked highest, as displayed in Table 25.

Evaluation Measures	Ad-Hoc	SAR	Deliberate Method	PM Direction	Change Driven
Percentage of Traceable Thresholds	=	+	+	+	+
Percentage of Capabilities Identified	=	+	+	+	=
Days to Plan Evaluation	+	=	=	=	+
Number of Traceable Thresholds Identified	=	+	+	+	+
Percentage of Shortfalls Identified	=	=	+	=	=
Quality of Planning Outputs	=	=	+	=	=
Number of C4I Systems Under Test	=	=	=	=	=
Percentage of Interfaces Identified	=	=	+	=	+
Total +	1	3	6	3	4
Total -	0	0	0	0	0
Overall Total	1	3	6	3	4

Table 25. JC3M System Alternatives Datum Design Comparison Matrix.
Initial Screening of Alternatives against Baseline (FEDOS)

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APPENDIX E. EVALUATION MEASURES DETAILS

FUNCTIONS AND EVALUATION MEASURES

Evaluation Measures (EM) were developed to tie to each function of the JC3M system, to ensure each function was not only measurable, but potentially capable of serving as a discriminator in considering alternative JC3M solutions.

In the following review of the functions of the JC3M system, the EMs are described in terms of their attributes, using a methodology described by the U.S. Army Training and Doctrine Command [Borman, 1993: 30].

Definition of the measure: A statement of the measure that includes directions for computation. Input data is identified for use in evaluation of alternatives.

Dimension of the measure: How the measure is expressed in terms of scale of measurement and unit of measure. The scale will be one of four categories [Pariseau, 1994].

Nominal – Nominal data is "named" data, which can be described, but cannot be manipulated arithmetically. Preferences cannot be implied from the label. Examples of nominal data sets include red, yellow, blue; eggs, chickens, cats; Marines, civilians, academics.

Ordinal – Ordinal data is "ordered" data, which can be assigned a location in a sequence, and a label designating that location. The interval between the values is not necessarily consistent. Ordinal data cannot be used to perform mathematical combinations or operations, other than a comparison of rank. Examples of ordinal data sets include First, Second, Third; A, B, C; Superior, Average, Marginal.

Interval – Interval data has a consistent scale, but the zero point is not absolute, and is only stipulated for convenience. Interval data values can be added and subtracted, but not multiplied or divided. Example interval data sets include temperature expressed on the Celsius or Fahrenheit scale (which do not have an absolute zero), or dates on a calendar.

Ratio - Ratio data incorporates all the attributes of the other categories, as well as an "absolute" zero point, which indicates a complete lack of the value being measured. The scale is consistent, and all arithmetic operations can be performed, including the calculation of ratios to express a relationship between values. Examples include age, temperature expressed on the Kelvin scale (which does have an absolute zero), and physical measurements (length, weight, height.)

Summation – Summation is the addition of a set of numbers; the result is their sum. Examples of "numbers" to be summed may be natural numbers, complex numbers, matrices.

Limits on the range of measure: Any limits on input or output of the measure.

Rationale for the measure: Why the measure was selected and what properties make it useful.

Relevance of the measure: Circumstances in which the measure would contribute to the decision process.

Associated measures: Other measures which may be used in conjunction with the measure, or which must be used with it to appropriately evaluate the issue.

(1.0) Plan C4I SoS Evaluation

Planning is the function that drives the content of an evaluation. The planning function identifies the resources required to evaluate the performance of a C4I SoS.

(1.1) Define Problem (Figure 48)

Determination of the SoS capabilities and operating conditions to be considered in the SoS evaluation.

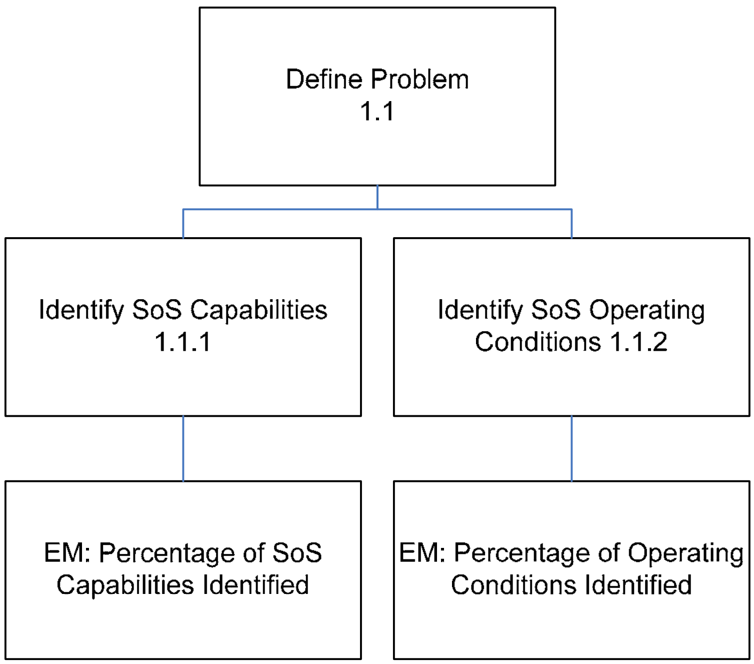

Figure 48. Define Problem.

Functional breakdown of Define Problem (1.1) with evaluation measures

(1.1.1) Identify SoS Capabilities

How well does this alternative define the capabilities of the SoS to be evaluated?

EM #1: Percentage of SoS Capabilities Identified

1. Definition of the Measure:

   This EM is calculated by dividing the count of SoS capabilities identified by the alternative by total SoS capabilities. Input data is the number of SoS capabilities.

2. Dimension of the Measure:

Ratio – percentage of capabilities identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent

4. Rationale for the Measure:

   This measure directly addresses the ability of the alternative to effectively identify capabilities.

5. Relevance of the Measure:

   The measure may be used to compare alternative JC3M solutions under the same conditions.

6. Associated Measures:

   Percentage of Operating Conditions Identified

(1.1.1) Identify SoS Operating Conditions

How well does this alternative identify the conditions under which the SoS will be evaluated?

EM #1: Percentage of Operating Conditions Identified

1. Definition of the Measure:

   This EM is calculated by dividing the count of SoS operating conditions identified by the alternative JC3M solution by total SoS operating conditions. Input data is the list of SoS operating conditions, including time of day, location, physical environment, and distance.

2. Dimension of the Measure:

   Ratio – percentage of operating conditions identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

This measure directly addresses the ability of the alternative to effectively identify operating conditions, and can be considered an indication of the flexibility of the alternative to process complex SoS. Understanding the environment in which the SoS will be used will support testing to the same requirements. Does this alternative identify the fleet or field environment the SoS was intended to perform in?

5. Relevance of the Measure:

   The measure may be used to compare alternative JC3M solutions under the same conditions.

6. Associated Measures:

   Percentage of SoS Capabilities Identified

(1.2) Define Components (Figure 49)

Identify the System(s) Under Test (SUT) – those individual systems that comprise the SoS, and will be included in the
evaluation.

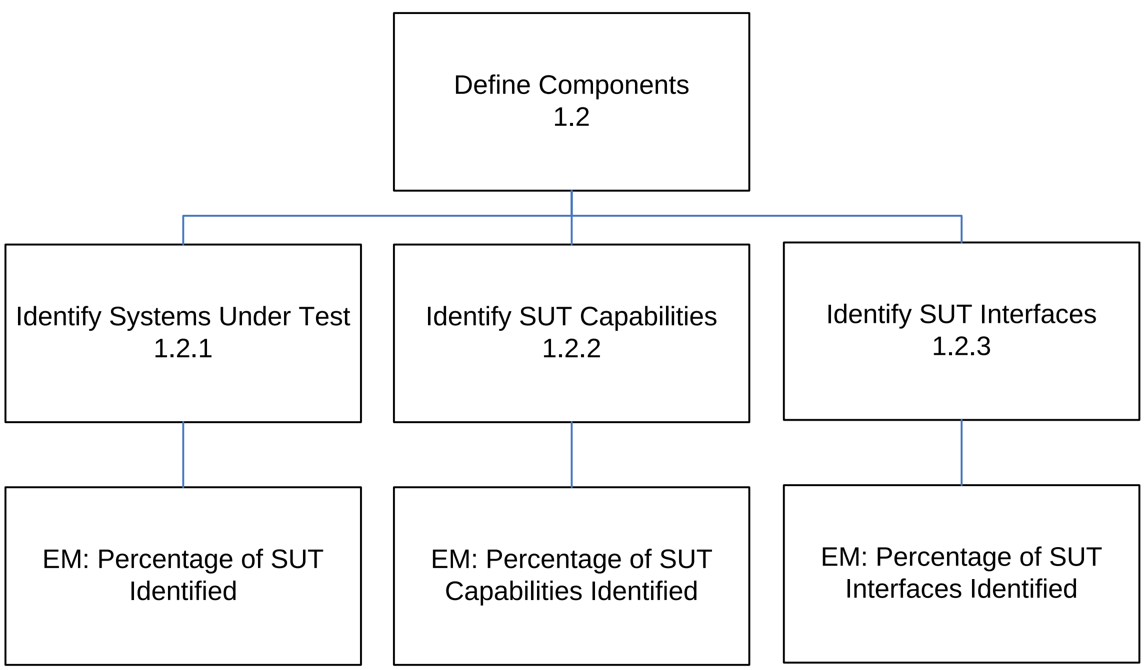

Figure 49. Define Components.

Functional breakdown of Define Components (1.2) with evaluation measures

(1.2.1) Identify Systems Under Test

How well does this alternative identify SUT required for the SoS evaluation?

EM #1: Percentage of SUT Identified

1. Definition of the Measure:

   This EM is calculated by dividing the count of SUT identified by the alternative by total SUT count. Input data is the number of SUT, resident in the SoS, required for the evaluation.

2. Dimension of the Measure:

   Ratio – percentage of SUT identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify SUT.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

(1.2.2) Identify SUT Capabilities

How well does this alternative identify capabilities the SUT(s) must perform to support the SoS evaluation? Function 1.1.1 identifies the SoS Capabilities; this function identifies the capabilities of the system(s) participating in the evaluation.

EM #1: Percentage of SUT Capabilities Identified

1. Definition of the Measure:

This EM is calculated by dividing the count of SUT capabilities identified by the alternative by total SUT capabilities. Input data is the number of SUT capabilities.

2. Dimension of the Measure:

   Ratio – percentage of capabilities identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify capabilities.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Percentage of SoS capabilities identified.

(1.2.3) Identify SUT Interfaces

How well does this alternative identify interfaces between SUT which are required to support the SoS evaluation?

EM #1: Percentage of SUT Interfaces Identified

1. Definition of the Measure:

   This EM is calculated by dividing SUT interfaces identified by the alternative by the total SUT interfaces. Input data is the number of SUT interfaces.

2. Dimension of the Measure:

   Ratio – percentage of interfaces identified.

3. Limits on the range of Measure:

The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify interfaces.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions

6. Associated Measures:

   None

(1.3) Define Evaluation Criteria (Figure 50)

Determination of the Resources required to conduct the evaluation, and criteria used when evaluating the SoS.

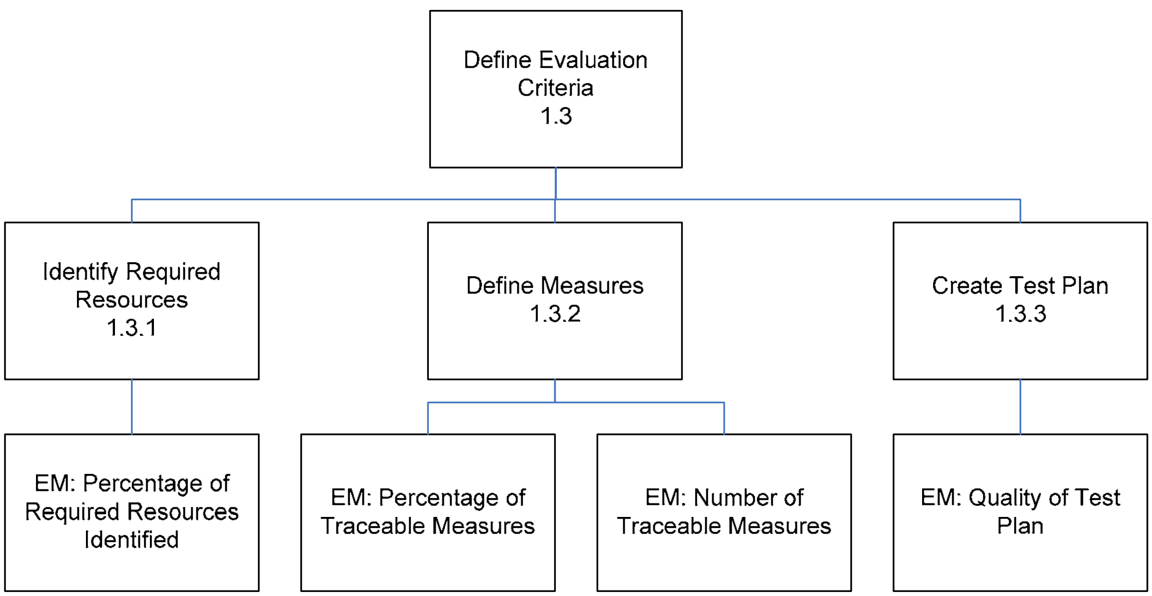

Figure 50. Define Evaluation Criteria.

Functional breakdown of Define Evaluation Criteria (1.3) with evaluation measures

(1.3.1) Identify Required Resources

How well does this alternative identify resources (people, time, equipment, etc.) required to conduct the SoS evaluation?

EM #1: Percentage of Required Resources Identified

1. Definition of the Measure:

   This EM is calculated by dividing the count of resources identified by the alternative JC3M solution by total resources required. Input data is the number of resources required for SoS evaluation, including personnel, facilities, C4I systems, training, and services.

2. Dimension of the Measure:

   Ratio – percentage of resources identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify required resources.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None

(1.3.2) Define Measures

How well does this alternative identify measures of performance when evaluating the SoS?

EM #1: Percentage of Traceable Measures

1. Definition of the Measure:

   This EM is calculated by dividing the number of measures (traceable to stakeholder requirements) generated by the alternative, by the number of measures generated by the alternative. Input data is the list of stakeholder requirements.

2. Dimension of the Measure:

   Ratio – percentage of traceable measures identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent. .

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify measures.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

EM # 2: Number of Traceable Measures

1. Definition of the Measure:

   Number of Traceable Measures is calculated by summing the number of measures, traceable to stakeholder requirements, generated by the alternative. Input data is the list of stakeholder requirements.

2. Dimension of the Measure:

   Interval – total of traceable measures identified.

3. Limits on the range of Measure:

   Output is a real number greater than or equal to zero.

4. Rationale for the Measure:

   The measure addresses the ability of the alternative to perform a core function of JC3M, and identify measures.

5. Relevance of the Measure:

The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

(1.3.3) Create Test Plan

How well does the alternative create test plans?

EM #1: Quality of Test Plan

1. Definition of the Measure:

   This EM is calculated by assigning an overall quality level to the test plan produced by the alternative. Input data is the list of JC3M internal and external documents.

2. Dimension of the Measure:

   Ordinal – Low, Medium, High.

3. Limits on the range of Measure:

   Output is a qualitative ranking of the outputs.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to create effective test plans.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions

6. Associated Measures:

   None

(1.4) Ensure Evaluation Readiness (Figure 51)

Review plans and assumptions to ensure required resources are available, or that a remediation plan is in place. Identification of shortfalls will determine if the evaluation can continue, or if additional planning is required. The review is designed to ensure expectations and risks are correctly identified. Before the evaluation begins, all stakeholders must agree that requirements, expectations, and risks are accurately identified, conflicts resolved or noted, and remediation plans are in place. When the review is completed, measures are gathered on the conduct of the entire planning phase.

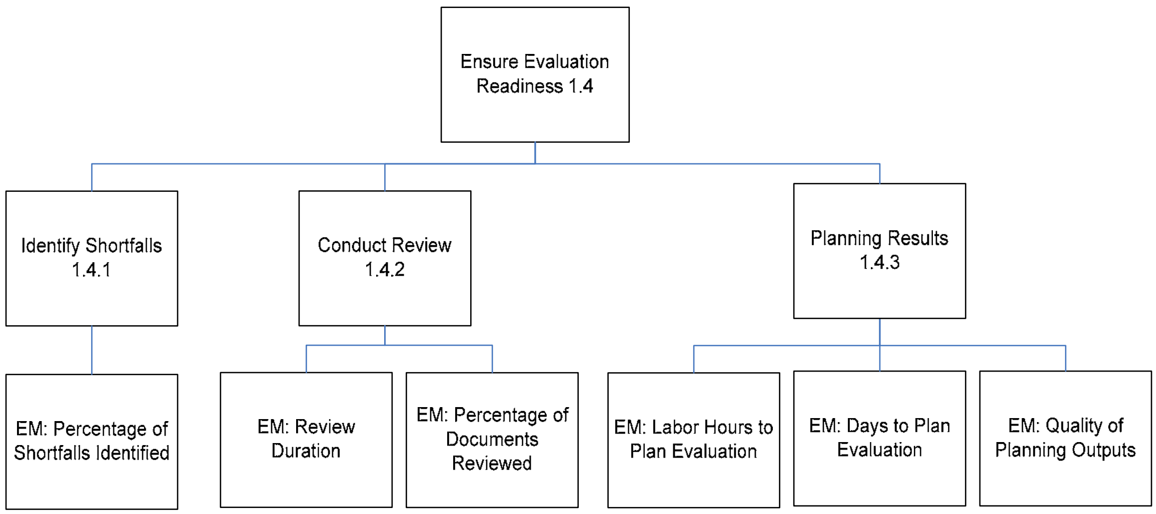

Figure 51. Ensure Evaluation Readiness.

Functional breakdown of Ensure Evaluation Readiness (1.4) with evaluation measures

(1.4.1) Identify Shortfalls

How well does this alternative identify gaps between resources required to evaluate the SoS and the resources included in the plan for SoS evaluation?

EM #1: Percentage of Shortfalls Identified

1. Definition of the Measure:

   This EM is calculated by dividing the number of resource shortfalls identified by the alternative, by the total number of shortfalls. Input data to be used is the list of required resources and known shortfalls.

2. Dimension of the Measure:

   Ratio – percentage of resource shortfalls identified.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to identify missing or incomplete resources.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

(1.4.2) Conduct Review

How long does the alternative take to review the evaluation plan with the stakeholders?

EM #1: Review Duration

1. Definition of the Measure:

   This EM is calculated by summing the total duration of the evaluation plan review.

2. Dimension of the Measure:

   Ratio – time in hours.

3. Limits on the range of Measure:

   Output is a real number greater than or equal to zero.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to conduct readiness reviews.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Percentage of Documents Review Quality of JC3M Documents

EM #2: Percentage of documents reviewed

1. Definition of the Measure:

   This EM is calculated by dividing the number of JC3M internal and external documents (to included SE Artifacts) reviewed by the total number of JC3M internal and external documents.

2. Dimension of the Measure:

   Ratio - percentage of documents reviewed.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to review JC3M documents effectively.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Review Duration

   Quality of JC3M Documents

(1.4.3) Planning Results

How long did this alternative take to execute the planning phase take, and what were the results?

EM # 1: Hours to Plan Evaluation

1. Definition of the Measure:

At the completion of the review, this EM is calculated by summing the labor man-hours required to plan an evaluation. Input data is the duration of each Planning task, as performed by the alternative. Note that this data was not used to directly compare the performance of alternatives. Rather, this data was used in the LCCE to calculate the personnel costs associated with performance of tasks by an alternative.

2. Dimension of the Measure:

   Summation – duration of evaluation planning.

3. Limits on the range of Measure:

   Output is a real number greater than or equal to zero.

4. Rationale for the Measure:

   This measure addresses the labor hours used in the planning phase of JC3M system, and indirectly addresses the duration of JC3M system evaluations.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Days to Plan Evaluation.

   Quality of Planning Outputs.

EM # 2: Days to Plan Evaluation

1. Definition of the Measure:

   At the completion of the review, this EM is calculated by summing the days required to plan an evaluation. Input data is the duration of each Planning task, as performed by the alternative.

2. Dimension of the Measure:

Ratio – duration of evaluation planning in days.

3. Limits on the range of Measure:

   Output is a real number greater than or equal to zero.

4. Rationale for the Measure:

   This measure addresses the duration of the planning phase of JC3M system, and indirectly addresses the duration of JC3M system evaluations.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Hours to Plan Evaluation.

   Quality of Planning Outputs.

EM #3: Quality of Planning Outputs

1. Definition of the Measure:

   At the completion of the review, this EM is calculated by assigning an overall quality level to the planning documents produced by the alternative. Input data is the list of JC3M system internal and external documents.

2. Dimension of the Measure:

   Ratio - from 1 - 4 (Likert Scale.)

3. Limits on the range of Measure:

   Output is a qualitative ranking of the JC3M internal and external documents.

4. Rationale for the Measure:

This measure addresses the ability of the alternative to create effective JC3M documents.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Hours to Plan Evaluation

   Days to Plan Evaluation

(2.0) Evaluate Capability of C4I SoS

Test agencies will use JC3M to evaluate the performance of the SoS. JC3M does not include new processes, and instead relies on existing Joint and Service processes for the conduct of C4I SoS evaluations. Because JC3M relies on existing processes, this function is not explicitly modeled, nor are there defined evaluation measures.

Modeling and simulation is highly recommended as part of the conduct of any C4I SoS evaluation.

(3.0) Report Results

Test and acquisition agencies will use JC3M to report the results of an evaluation because the existing process which do in fact clearly indicate pass or fail based on meeting or not meeting a set of thresholds can no longer be used. Therefore, the reporting system needs to be different to reflect the results in a form of "here is what the system does" and allow the end-user to say if it's good enough.

The evaluation and the planning for the evaluation do not focus on creating the threshold values but rather focus on finding and defining more reasonable evaluation measures that make more sense to an end-user, but not defining "how good is good."

(4.0) Adaptability (Figure 52)

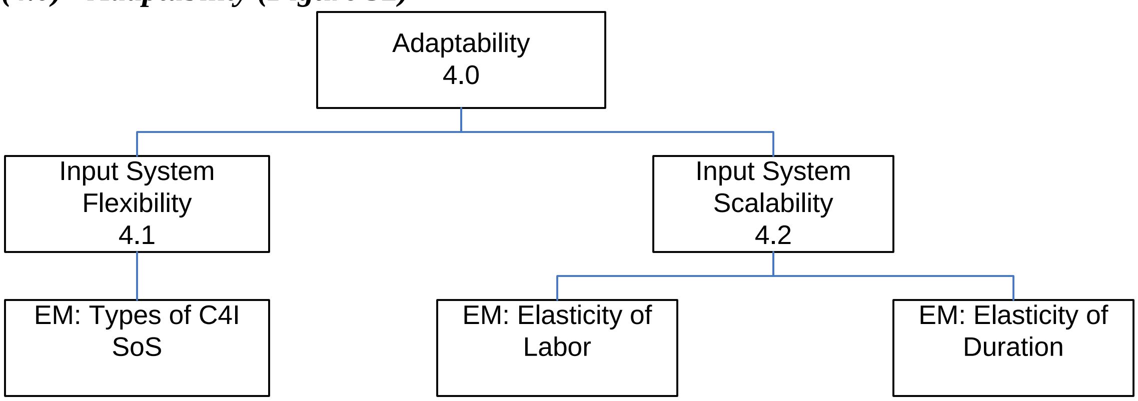

Figure 52. Adaptability.

Non-functional breakdown of Adaptability (4.0) with Evaluation Measures

(4.1) Input System Flexibility

How well does the alternative support varying types of C4I SoS?

EM #: 1 Types of C4I SoS

1. Definition of the Measure:

   This EM is calculated by recording the type of SoS the alternative can evaluate. Input data is the list of SoS types.

2. Dimension of the Measure:

   Nominal – Joint, Service, both.

3. Limits on the range of Measure:

Output is a list of SoS types supported by the alternative.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to evaluate varying types of C4I SoS.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Number of C4I SUT

(4.2) Input System Elasticity

How does the alternative respond when the SoS evaluation changes scope?

EM #: 1 Elasticity of Labor

1. Definition of the Measure:

   This EM is calculated dividing the percent change in systems under test by the percent change in labor hours to conduct the planning phase of JC3M.

2. Dimension of the Measure:

   Ratio – percentage change.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to plan C4I SoS of varying sizes.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Elasticity of Duration

EM # 2: Elasticity of Duration

1. Definition of the Measure:

   This EM is calculated dividing the percent change in systems under test by the percent change in duration to conduct the planning phase of JC3M.

2. Dimension of the Measure:

   Ratio – percentage change.

3. Limits on the range of Measure:

   The output can assume any value from 0 to 100 percent

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to plan C4I SoS of varying sizes.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   Elasticity of Labor

(5.0) Usability (Figure 53)

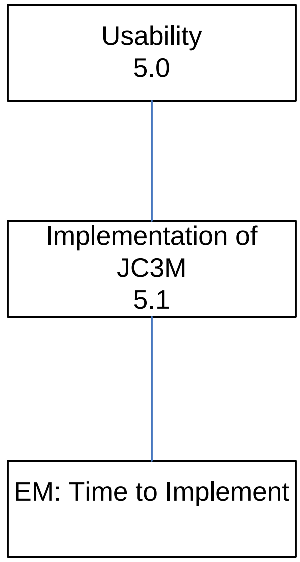

Figure 53. Usability.

Non-functional breakdown of Usability (5.0) with evaluation measure.

(5.1) Implementation of JC3M

What resources are required to implement the alternative? What is the duration of the implementation process, i.e. the time required to replace the baseline process with the alternative?

EM # 1: Time to implement JC3M

1. Definition of the Measure:

   This EM is calculated by summing the time required to implement the alternative. Input data is based on calculated implementation time.

2. Dimension of the Measure:

   Ratio – duration of implementation.

3. Limits on the range of Measure:

   Output is a real number greater than or equal to zero.

4. Rationale for the Measure:

This measure addresses the duration of implementation, and indirectly addresses the cost of implementing the alternative.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

(6.0) Repeatability (Figure 54)

One goal of JC3M is to produce the same outputs for each SoS evaluation. If JC3M consistently produces products at the same level of quality, for a variety of scenarios, it has high repeatability. As scenarios vary, what is the effect on the quality of the output from the alternative?

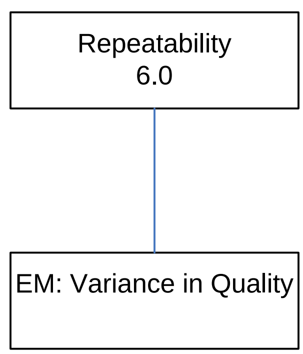

Figure 54. Repeatability.

Non-functional breakdown of Repeatability (6.0) with evaluation measure

EM # 1: Variance in Quality

1. Definition of the Measure:

   This EM is calculated by assigning an overall quality level to the products produced by the alternative in varying scenarios. This EM is not just measuring the quality level, but the difference in the quality level between the different scenarios. Input data is the list of JC3M internal and external documents.

2. Dimension of the Measure:

Ordinal – Low, Medium, High.

3. Limits on the range of Measure:

   Output is a qualitative ranking of the outputs.

4. Rationale for the Measure:

   This measure addresses the ability of the alternative to create effective documents.

5. Relevance of the Measure:

   The measure may be used to compare alternatives under the same conditions.

6. Associated Measures:

   None.

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APPENDIX F. CORE IDEF0 DIAGRAMS

FEDOS IDEF0 Diagram

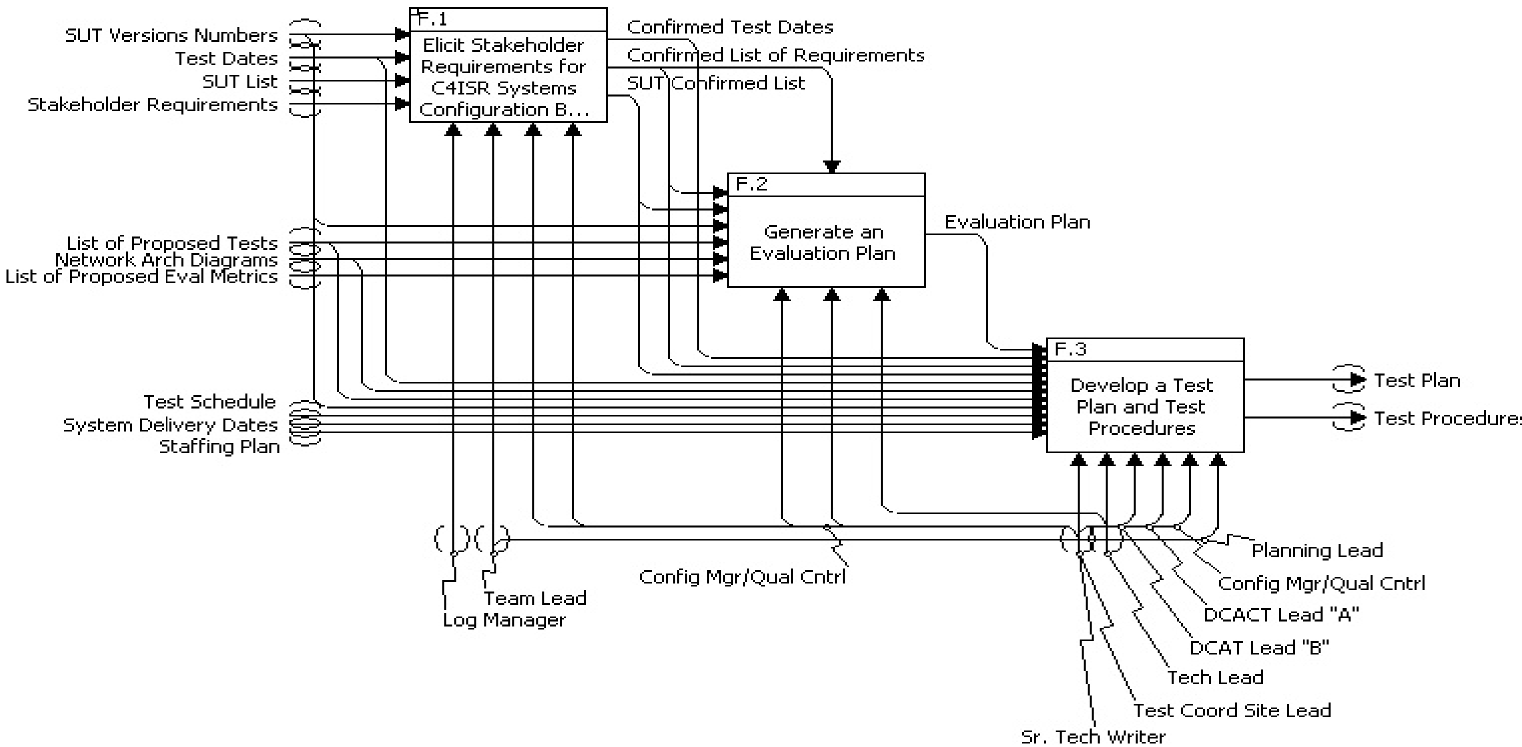

Figure 55. FEDOS IDEF0 Diagram.

This diagram illustrates only the FEDOS tasks performed in planning a C4I SoS Evaluation. Parentheses ("tunnels") on the left indicate stakeholder inputs or previous tasks. Test Plans and Procedures connect to the complete FEDOS C4I SoS evaluation process.

MC3T IDEF0 Diagram

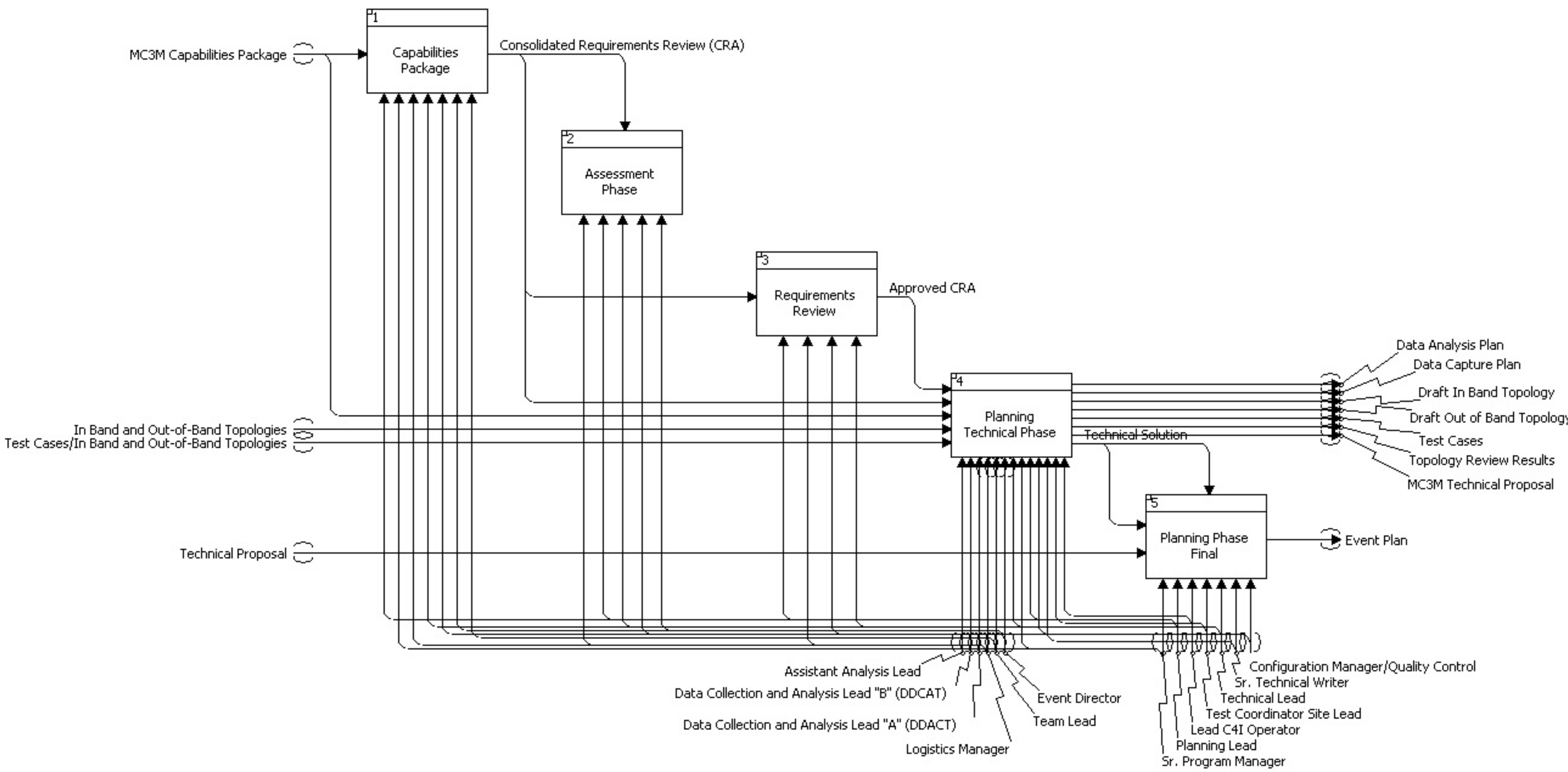

Figure 56. MC3T IDEF0 Diagram.

This diagram illustrates only the MC3T tasks performed in planning a C4I SoS Evaluation, and reflects MC3T naming and numbering conventions. Tunnels on the left indicate tasks and inputs to planning; tunnels on the right are used to indicate personnel inputs.

JTEM CTM IDEF0 Diagram

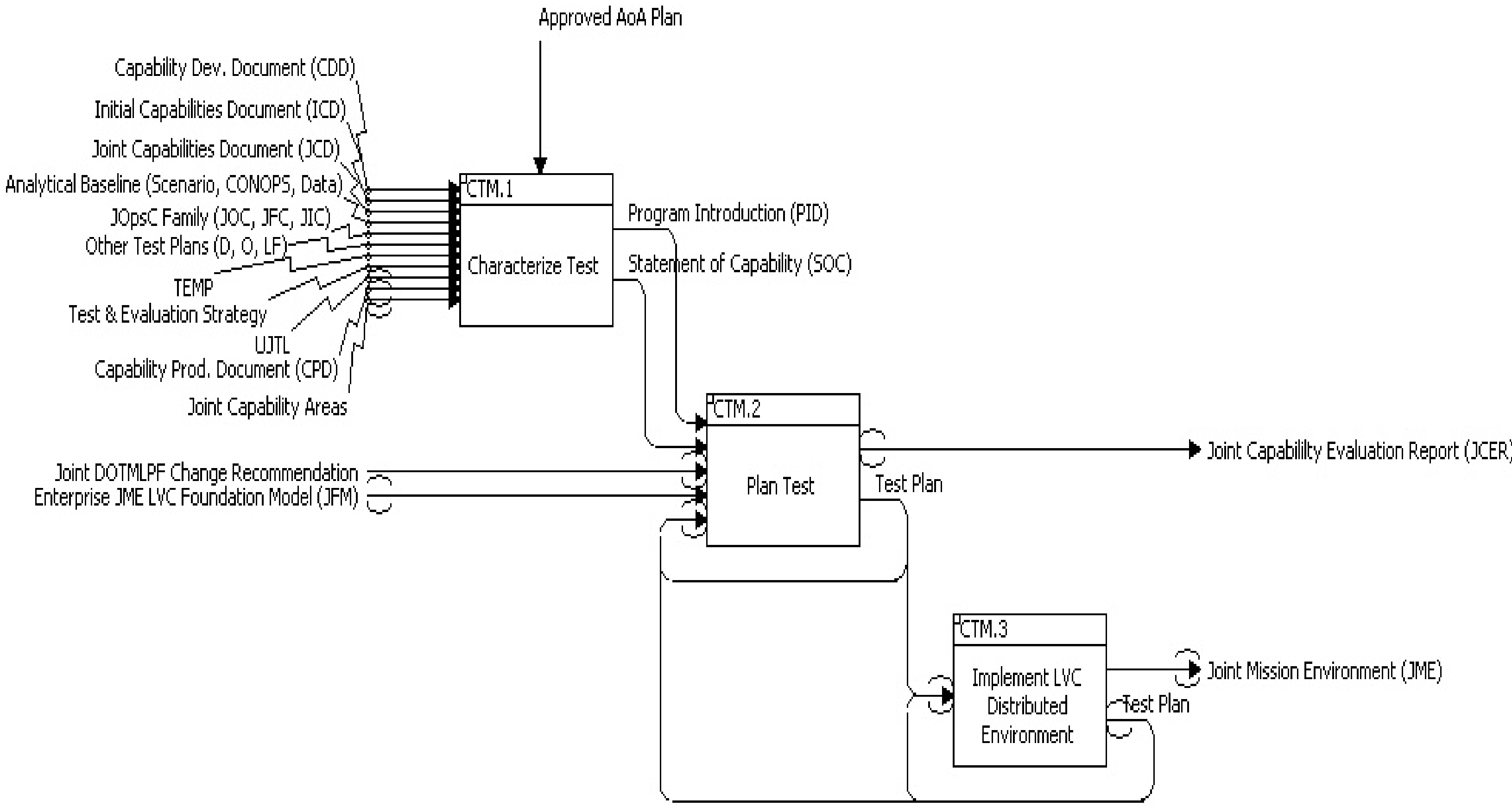

Figure 57. JTEM-CTM IDEF0 Diagram.

This diagram illustrates only the JTEM CTM tasks performed in planning a C4I SoS Evaluation, utilizes JTEM CTM naming and numbering conventions, and may change as the JTEM CTM matures.

FCB IDEF0 Diagrams

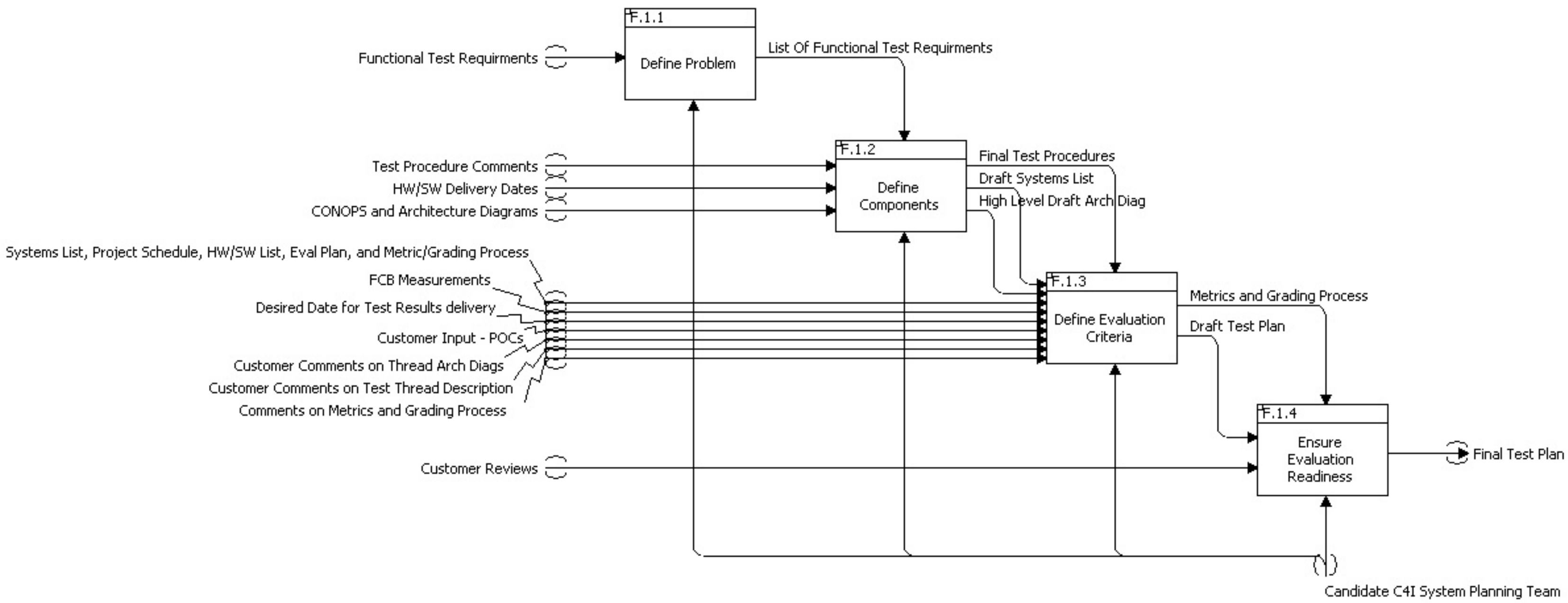

Figure 58. FCB IDEF0 Diagram.

This diagram illustrates only the FCB tasks performed in planning a C4I SoS Evaluation. Tunnels on the left indicate inputs to planning; Final Test Plan on the right was proposed for use with existing C4I SoS evaluation processes. “FCB Measurements” is the input from the C2 FCB. This is in comparison to the “SCR Measures” input seen in Figure 60.

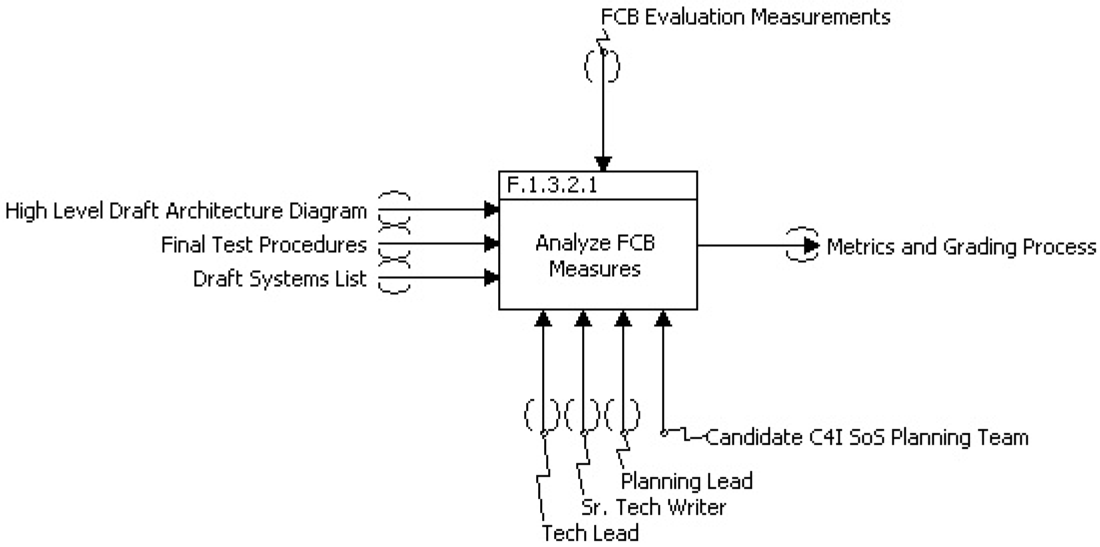

Figure 59. FCB's Analyze Measures task

This figure illustrates only FCB task 1.3.2.1 and how measures proposed by the FCB, and other inputs, would be analyzed by the test organization, and converted into metrics for use in the planning of a C4I SoS evaluation. 1.3.2.1 is a subset of FCB task 1.3 "Define Criteria" as seen in Figure 59.

SCR IDEF0 Diagrams

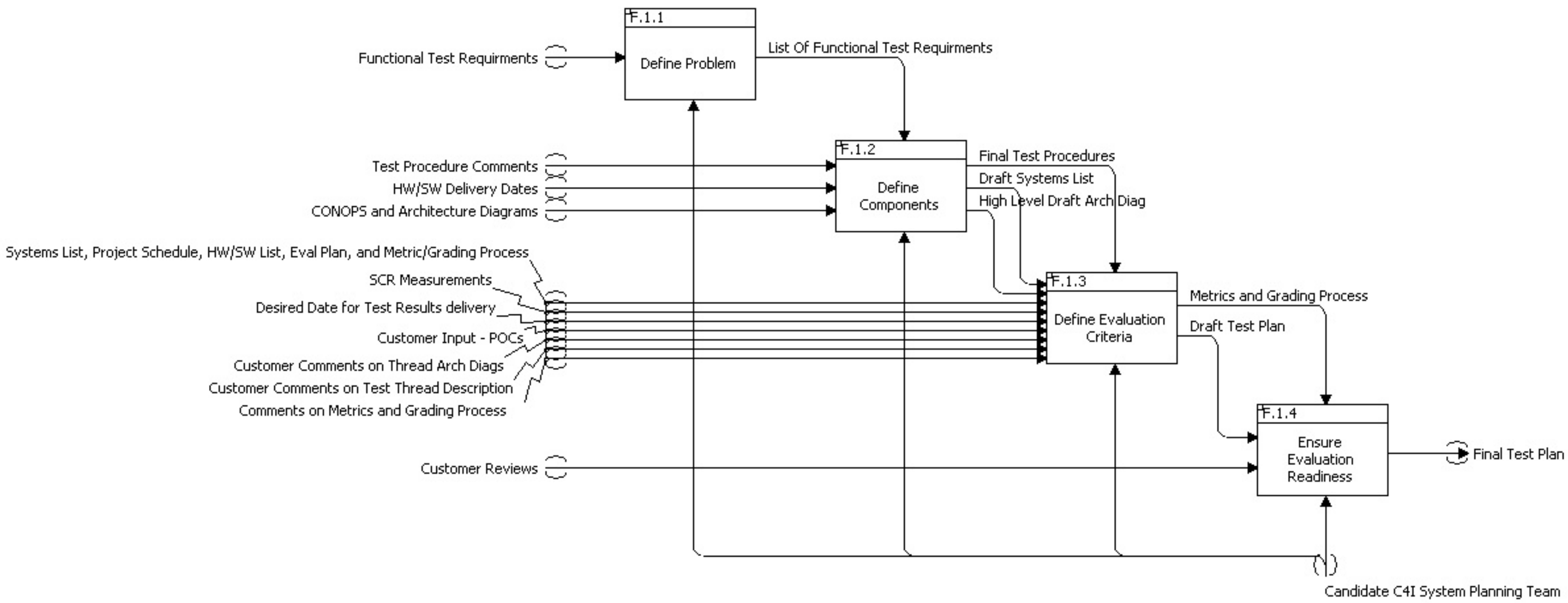

Figure 60. SCR IDEF0 Diagram.

This diagram shows illustrates only the SCR tasks performed in planning a C4I SoS Evaluation. Tunnels on the left indicate inputs to planning; Final Test Plan on the right was proposed for use with existing C4I SoS evaluation processes. “SCR Measurements” is the input to this task, generated within the test organization. This is in comparison to the “FCB Measures” input seen in Figure 58.

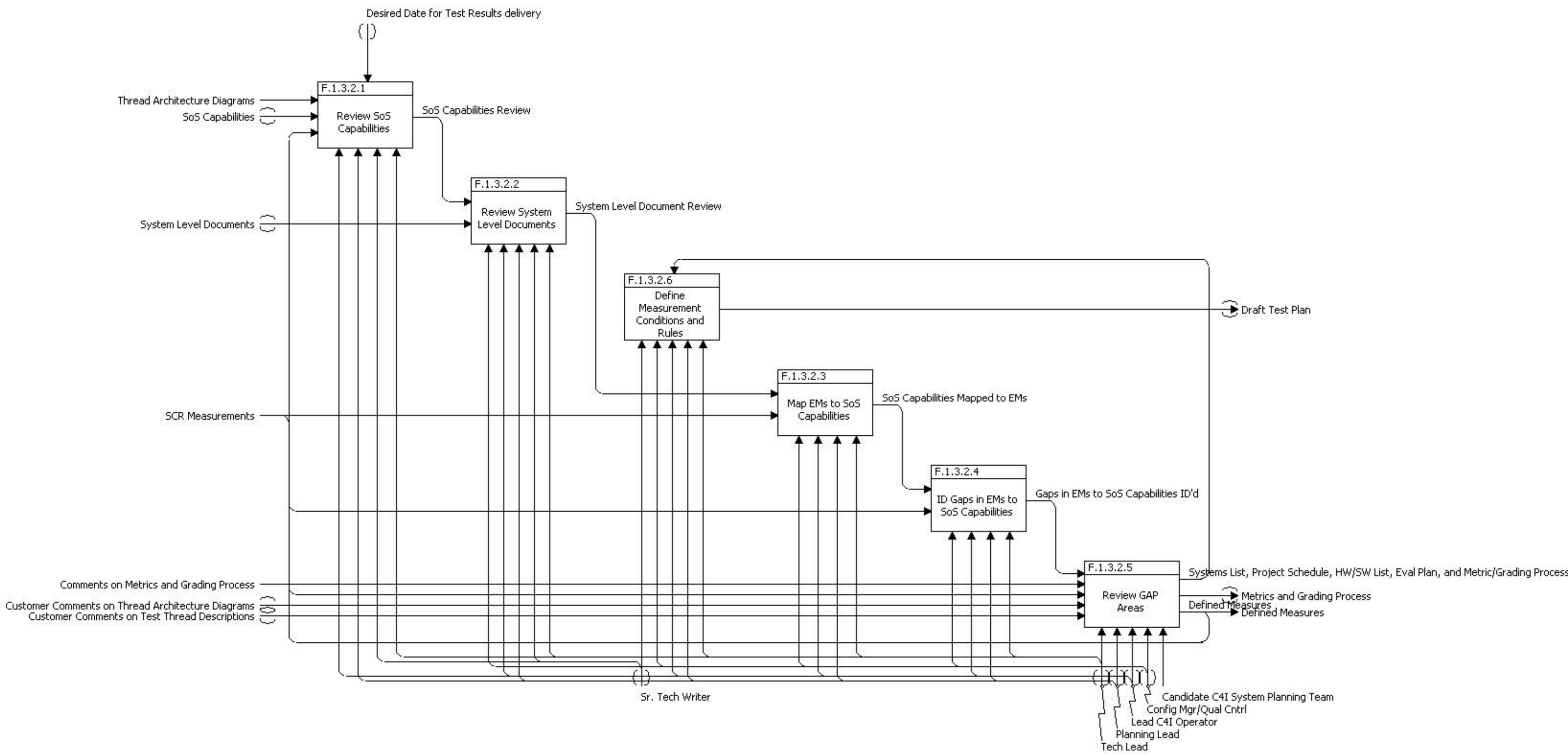

Figure 61. SCR's Define Measures task

This figure is a subset of SCR Task 1.3 in Figure 61, and illustrates a detailed view of how the SCR alternative would Define Measures. Inputs would be utilized by the test organization, and converted into metrics for use in the planning of a C4I SoS evaluation.

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APPENDIX G. EVALUATION MEASURE: PERCENTAGE OF TRACEABLE MEASURES

Percentage of Traceable Measures (PTM) was the EM for the Define Measures (1.3.2) function of the JC3M value hierarchy. The objective of the Define Measures function was to determine how well an alternative identifies measures of performance (MOP) when evaluating the SoS. An EM should not be confused with a MOP. EMs were measures created by this team to gauge functions of the JC3M system. MOPs are measures used to gauge performance of a C4I SoS.

Definition of PTM:

This EM was calculated by dividing the number of measures (traceable to stakeholder requirements) generated by the alternative, by the number of measures generated by the alternative.

$$PTM = \frac{\#\, Traceable\, Measures\, Created}{\#\, Total\, Measures\, Created} \qquad (5)$$

However, the team came to the conclusion that it was not feasible to calculate the PTM EM as it was defined because that would entail exercising each of the alternative systems and developing MOPs for each alternative. Therefore, a proxy measure was developed that could serve as an indicator to the performance of Define Measures function.

Proxy Definition of PTM:

This EM was calculated by taking the number of authoritative sources that were considered in the process and then dividing by the total number of authoritative sources available for the SoS.

$$PTM = \frac{\#\ Authoritative\, Sources\, Considered}{\#\ Authoritatative\, Sources\, Available} \qquad (6)$$

The concept was that analysts performing the Define Measures function should consider all available and appropriate documentation for the SoS. Considering all available documentation helped ensure that all requirements and testable capabilities were captured in the process and subsequently MOPs were defined for each. The team assumed that considering a wider set of authoritative sources would yield a higher number of requirements and capabilities, and in turn provide more metrics that are traceable. The team recognized that a Program Manager (PM) might be resistant to other sources used to define requirements for an SoS component system, when a CDD or ORD may have been used used for system-level requirements.

Figure 63 illustrates how measures are traceable to requirements for systems in acquisition programs. However, the JC3M problem statement is to consider evaluating SoSs that have been constructed or assembled with existing fielded systems. While component systems in the SoS do have CDDs or ORDs, the assembled SoS does not have CDDs, ORDs, or an overarching integrated architecture. This fact drives the need to obtain overall SoS requirements and measures from all relevant sources.

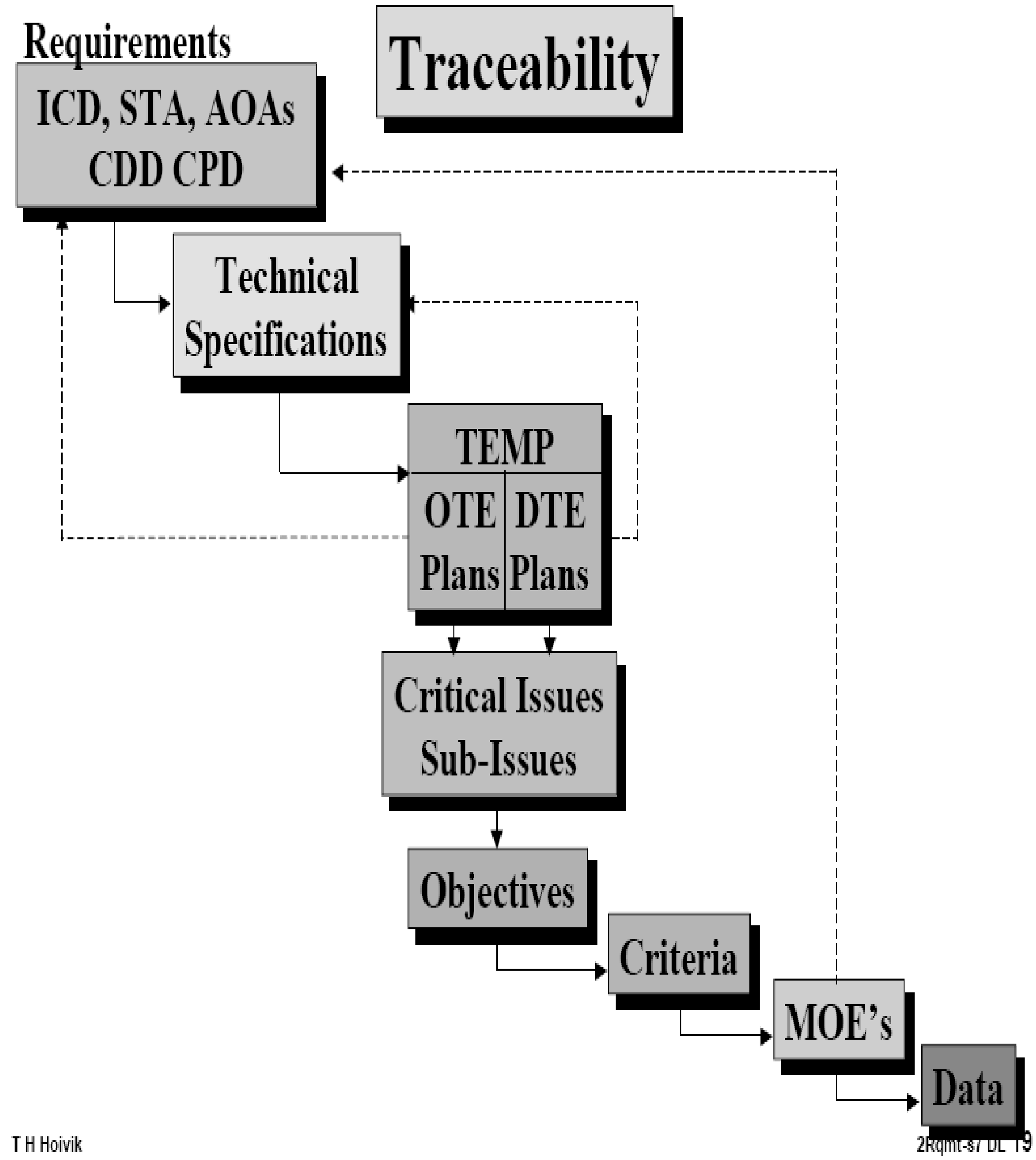

Figure 62. Performance Measure Traceability.

Performance Measures Trace Back to System Capabilities and Requirements [From Meyer, 2007].

Figure 63 illustrates how performance measures can be derived using an expanded set of authoritative sources. The next section describes the list of documents derived using various DoD Directives and Instructions.

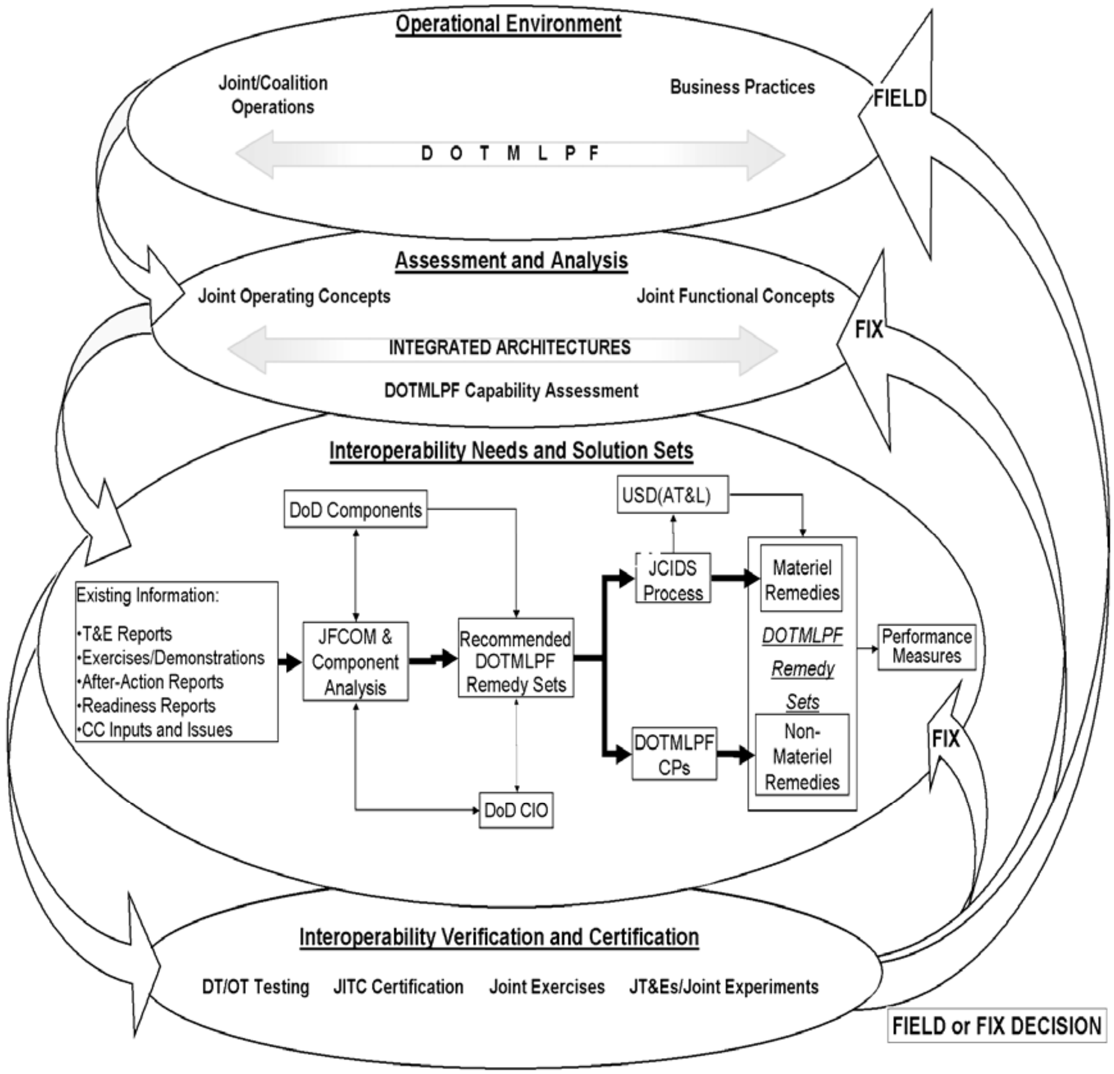

Figure 63. Fielded IT & NSS Interoperability Process.

Capability-focused, effects-based interoperability process for addressing operational warfighting interoperability and supportability issues for fielded IT and NSS [From DoDI 4630.8, 2004:26].

Building the PTM Denominator

The proxy definition for PTM states the total number of authoritative sources available for the SoS is the denominator of the measure. The team assembled a list of relevant documents from three categories: 1) reference documents, 2) system level documents and 3) overarching DoD documents. The reference documents include DoD Instructions (DoDI), DoD Directives (DoDD), and Combined Joint Chiefs of Staff Instructions (CJCSI.) The reference documents apply to all IT and NSS and provide specific requirements in determining interoperability needs. The system level documents are specific to any given system under test, and include system specific capabilities documents. Overarching DoD documents include Joint documents that are applicable across Services and or across different C4I systems; these include Joint Concept documents, Joint Doctrine, and integrated architectures.

a. Reference Documents

1. DoDD 5000.1, DoDI 5000.2
2. DoDD 4630.5 and DoDI 4630.8
3. DoDI 5200.40
4. DoDD 8500.01E
5. CJCSI 3170.01F
6. CJCSI 6212.01D
7. NCOW RM

b. Design Artifacts

1. JCIDS Capabilities Documents
   i) Joint Capabilities Document (JCD)
   ii) Initial Capabilities Document (ICD)
   iii) Capabilities Development Document (CDD) and Capabilities Production Document (CPD)

iv) Capstone Requirements Document (CRD)

2. System Threat Assessment (STA)
3. Analysis of Alternatives (AOA)
4. Information Support Plan (ISP)
5. Test and Evaluation Master Plan (TEMP)
6. Test Plans
7. Data Management and Analysis Plans (DMAP)
8. Reports from T&E, exercises, and readiness reports
9. Combatant Commanders Input and Issues

c. Overarching DoD Documents

1. Joint Doctrine
2. Universal Joint Task List (UJTL), Service task lists, and Mission Essential Task Lists (METLs)
3. Joint Operating Concepts (JOC)
4. Joint Functional Concepts (JFC)

Description of Applicability of Documents

The list was built using guidance from [DoDD 4630.5, 2004: 3] which states that all IT and NSS interoperability and supportability needs shall be derived using Joint Operating Concepts, Joint Functional Concepts, and associated integrated architectures and shall be updated as necessary throughout the system's life. IT and NSS interoperability and supportability needs, for a given capability, shall be identified through the following:

1. The Defense Acquisition System (as defined in the 5000 series of DoD issuances)
2. The Joint Capabilities Integration and Development System (JCIDS) process.

3. The Doctrine, Organization, Training, Materiel, Leadership and education, Personnel and Facilities (DOTMLPF) change recommendation process.

In addition, Universal Reference Resources (URRs) are resources that must be consulted when building integrated architecture products for IT and NSS. URRs are: "…DoD Architecture Framework; DoD Core Architecture Data Model; Universal Joint Task List; Technical Reference Model; Global Information Grid (GIG) Architecture; DoD Net-Centric Data Strategy; DoD Metadata Registry; NCOW RM; and the DISR" [DoDD 4630.5, 2004: 57].

"Integrated Architectures shall be used as the basis for assessment and analysis to characterize interoperability needs for a given capability. Solutions to the identified needs may be materiel or non-materiel solution sets, or both. Interoperability needs shall be documented in applicable capabilities documents and the NR-KPP. System information and interoperability dependencies and supportability requirements shall be documented in an ISP. Regardless of the solution (materiel or non-materiel), interoperability and supportability shall be tested and verified prior to operational use or fielding" [DoDI 4630.8, 2004: 22].

The remainder of this section provides more detail on the list of documents.

DoDD 5000.1

This directive applies to all DoD acquisition programs. DoD policy is to translate operational needs into stable, affordable programs (e.g., through integrated product & process development, long-range investment plans, risk management, use of a "cost as an independent variable" approach, performance specifications), acquire quality products (e.g., based on competition, test & evaluation, modeling & simulation, past performance, experience in domain, mature software process), organize for efficiency & effectiveness (e.g., streamlined organization, trained acquisition corps, teams, tailoring, automated acquisition information corps, teams, tailoring, automated acquisition information) and make use of test and evaluation criteria as the basis of managing an acquisition program [DoDD 5000.1, 2003: 2].

Enclosure 1 to the directive provides additional policies on independent operational test agencies, information assurance, information superiority, integrated test and evaluation, and interoperability [DoDD 5000.1, 2003: 7].

DoDI 5000.2

This instruction implements DoDD 5000.1, and applies primarily to defense technology projects and acquisition programs, but some requirements are solely for Major Defense Acquisition Programs and Major Automated Information Systems. The instruction "establishes a simplified and flexible management framework for translating mission needs and technology opportunities, based on approved mission needs and requirements, into stable, affordable, and well-managed acquisition programs" [DoDI 5000.2, 2003: 1].

The instruction identifies test and evaluation procedures for major acquisition programs and major automated information systems and provides procedures for assessing information interoperability, C4I support, and information assurance. These procedure are limited to ACAT I or IA programs and special interest programs designated by the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD C3I.) The instruction also establishes procedures for integrated architectures and defines the responsibilities of a PM on development, operational, interoperability, and information assurance tests.

DoDD 4630.5

This directive defines a capability-focused, effects-based approach for IT and NSS interoperability and supportability across DoD. The directive establishes Net-Ready Key Performance Parameters (NR-KPP) to assess attributes required for the technical information exchange and end-to-end operational effectiveness of the exchange [DoDD 4630.5, 2004: 1].

DoDI 4630.8

This instruction implements a capability-focused, effects-based approach to IT and NSS interoperability and supportability throughout DoD in order to ensure their life-cycle interoperability and supportability, and implements NR-KPP [DoDI 4630.8, 2004: 25].

DoDI 5200.40

This instruction describes policies, processes, and the importance of IT security certification and accreditation in the acquisition of IT systems [DoDI 5200.40, 1997: 1].

DoDD 8500.1E

This directive establishes policy for Information Assurance (IA) and assigns responsibilities to achieve DoD IA and supports the evolution to network centric warfare [DoDD 8500.1E, 2002: 1].

CJCSI 3170.01F

This instruction describes JCIDS [CJCSI 3170.01F, 2007] and the identification, assessment, and prioritization of joint military capabilities needs. The instruction implements a capabilities based approach for identifying gaps in existing capabilities and developing new capabilities. The instruction also provides guidelines for JCD, ICD, and CDD production and use, as well as CPD and DOTMLPF change recommendations.

CJCSI 6212.01D

This instruction identifies information needs, dependencies, and interfaces for IT and NSS programs in all acquisitions, focusing on net-readiness, interoperability, information supportability, and information sufficiency concerns. The instruction provides guidance on the use of the Information Support Plan (ISP) and interoperability evaluation and certification procedures [CJCSI 6212.01D, 2006].

1. Appendix A to Enclosure C provides guidance on the use of the ISP (C4ISP) Assessment tool and detailed ISP review procedures [CJCSI 6212.01D, 2006: C-A-1].

2. Appendix B to Enclosure C Provides guidelines for a Tailored Information Support Plan (TISP), including waivers, content, and certification [CJCSI 6212.01D, 2006: C-B-1].

3. Enclosure D defines the submission of NR-KPP documentation and describes JCIDS and ISP Document considerations; JCD, ICD, CDD, CPD, and ISP production;

the interoperability certification process; Global Information Grid (GIG) Key Interface Profile (KIPs); and IA requirements [CJCSI 6212.01D, 2006: D-1].

4. Enclosure E provides guidelines for Joint interoperability testing and certification [CJCSI 6212.01D, 2006: E-1].

Joint Doctrine

There are 76 Joint Doctrine Publications covering Personnel, Intelligence, Operations, Logistics, Plans, and Communications Systems support. Applicable Joint Doctrine Publications will be reviewed depending on the system under test.

Universal Joint Task List (UJTL), Service task lists, and Mission Essential Task Lists (METLs)

The Universal Joint Task List (UJTL) [CJCSM 3500.04D, 2005], when augmented with Service task lists, is a comprehensive list of tasks, conditions, measures, and criteria supporting all levels of the Department of Defense in executing the National Military Strategy. Mission Essential Task Lists (METL) organize tasks by mission. Thus a METL is a compilation of tasks, with associated standards and conditions. The UJTL, Service Task lists METL will be used to identify tasks that the system under test, as part of the SoS, must perform.

Applicable Joint Operating Concepts (JOC) and Joint Functional Concepts (JFC)

[DoDD 4630.5, 2004: 13] states all IT and NSS interoperability and supportability needs shall be derived using Joint Operating Concepts and Joint Functional Concepts. JOCs and JFCs applicable to the C4I SoS under evaluation should also be reviewed. There are currently 6 JOC publications.

1. Homeland Defense and Civil Support [DoD JOC HDCS, 2006]
2. Deterrence Operations [DoD JOC DO, 2006]
3. Major Combat Operations [DoD JOC MCO, 2006]
4. Stability Operations [DoD JOC SO, 2006]
5. Irregular Warfare [DoD JOC IW, 2007]
6. Military Support to Shaping Operations [DoD JOC MSSO, 2007]

There are currently 8 JFC publications:

1. Training [DoD JFC T, 2007]
2. Force Management [DoD JFC FM, 2005]
3. Net Centric [DoD JFC NC, 2005]
4. Battlespace Awareness [DoD JFC BA, 2003]
5. Command and Control [DoD JFC C2, 2007]
6. Force Application [DoD JFC FA, 2004]
7. Focused Logistics [DoD JFC FL, 2003]
8. Protection [DoD JFC P, 2004]

Determining the Score for the PTM Evaluation Measure

If an alternative considers every document in the comprehensive list of authoritative documents discussed in the previous section it receives a score of 100%. Table A-1 contains the comprehensive list of authoritative documents, weights for each document, and the score for each alternative. If an alternative uses a document in its process then the alternative receives the complete score for that document.

Based on a number of 25 authoritative sources, if each source were weighted equally each would have a score of 4. However, the team felt that there were some sources that would contribute more to the Define Measures function than others. Therefore, scores were derived on a scale of 2, 4, and 8. A score of 2 was given to sources that were considered by the team to have the least contribution to deriving measurable requirements yet still essential. Scores of 4 were given to sources that were cited in references as being essential. For example, DoDD 4630.5 [2004: 13] states that it is DoD policy that interoperability and supportability needs shall be derived using Joint Operating Concepts and Joint Functional Concepts. Scores of 8 were given to all the JCIDs Capability documents which were deemed as the most important sources by the team.

Authoritative Source	Score	Baseline	CTM	MC3T	FCB	SCR
a. Reference Documents (Weight incl. 1-7)	**16%**	n/a	**16%**	**0%**	**16%**	**16%**
1. DoDD 5000.1 and 5000.2	2%	n/a	2%	0%	2%	2%
2. DoDD 4630.5 and DoDI 4630.8	2%	n/a	2%	0%	2%	2%
3. DoDI 5200.40	2%	n/a	2%	0%	2%	2%
4. DoDD 8500.1 (IA)	2%	n/a	2%	0%	2%	2%
5. CJCSI 3170 (J8)	2%	n/a	2%	0%	2%	2%
6. CJCSI 6212.01D (J6)	2%	n/a	2%	0%	2%	2%
7. NCOW Reference Model	4%	n/a	4%	0%	4%	4%
b. Design Artifacts (Weight incl. 1-19)	**68%**	n/a	**60%**	**56%**	**56%**	**60%**
1. JCIDS Documents (Weight incl. i-iv)	**32%**	n/a	**32%**	**32%**	**32%**	**32%**
i) JCD	8%	n/a	8%	8%	8%	8%
ii) ICD	8%	n/a	8%	8%	8%	8%
iii) CDD and or CPD	8%	n/a	8%	8%	8%	8%
iv) CRD	8%	n/a	8%	8%	8%	8%
2. STA	4%	n/a	4%	0%	4%	0%
3. AoA	4%	n/a	0%	0%	4%	0%
4. ISP	4%	n/a	0%	0%	4%	4%
5. TEMP	8%	n/a	8%	8%	8%	8%
6. Test Plans	4%	n/a	4%	4%	0%	4%
7. Data Management and Analysis Plan (DMAP)	4%	n/a	4%	4%	0%	4%
8. Reports from T&E, exercises, and readiness reports	4%	n/a	4%	4%	0%	4%
9. Combatant Commanders Input and Issues	4%	n/a	4%	4%	4%	4%
c. Overarching DoD Docs. (Weight incl. 1-4)	**16%**	n/a	**16%**	**16%**	**16%**	**16%**
1. Joint Doctrine	4%	n/a	4%	4%	4%	4%
2. UJTL, Service task lists, METL	4%	n/a	4%	4%	4%	4%
3. JOC	4%	n/a	4%	4%	4%	4%
4. JFC	4%	n/a	4%	4%	4%	4%
Total	**100%**	**0%**	**92%**	**72%**	**88%**	**92%**

Table 26. Percent of Traceable Measures Summary Table

PTM Evaluation Measure detailed results by alternative.

APPENDIX H. GLOSSARY OF TERMS

Term	Definition
Action	Something done (a task or activity.)
Activity	A function, mission, action, or collection of actions.
Architecture	A framework or structure that portrays relationships among all the elements of the subject force, system, or activity.
Bandwidth	The difference between the limiting frequencies of a continuous frequency band expressed in hertz (cycles per second). The term bandwidth is also loosely used to refer to the rate at which data can be transmitted over a given communications circuit. In the latter usage, bandwidth is usually expressed in either kilobits per second or megabits per second.
C4ISR	Command, control, communications, computers, intelligence, surveillance, and reconnaissance
Capability	The ability to execute a specified course of action. (A capability may or may not be accompanied by an intention.)
Certification	Certification is the process of confirming that a system or component complies with its specified requirements and is acceptable for operational use.
Configuration Management	A discipline applying technical and administrative direction and surveillance to: (1) identify and document the functional and physical characteristics of a configuration item; (2) control changes to those characteristics; and (3) record and report changes to processing and implementation status.
Elasticity	A measure of the % change in one variable (x – the numerator) with respect to another variable (y – the denominator.) % change x > % change in y = Elastic; % change in x < % change in y = Inelastic.
Evaluation Measure	Scale to measure the degree that we attain an objective
Goal	Threshold of achievement
Interoperability	The ability of systems, units, or forces to provide data, information, materiel, and services to and accept the same from other systems, units, or forces, and to use the data, information, materiel, and services so exchanged to enable them to operate effectively together.
Measure of Effectiveness	A criterion used to assess changes in system behavior, capability, or operational environment that is tied to measuring the attainment of an end state, achievement of an objective, or creation of an effect.

Term	Definition
Measures of Performance	A criterion used to assess friendly actions that are tied to measuring task accomplishment.
Network	A group of components connected by communications.
Objective	Preferred direction of attainment of an evaluation consideration
Policy	A guiding principle or constraint, used to define general goals and acceptable criteria.
Process	Designated series of actions that produces some outcome.
Project Management Plan	A document that describes the background, goals, processes, resources, and schedule used to perform the project's tasks.
Quality Assurance	The process for monitoring a project to ensure that defined standards of quality are met.
Reliability	The probability that an item will perform its function under stated conditions of use and maintenance for a stated measure of the variant (time, distance, etc.)
Requirement	An approved need to achieve a capability, which is used in turn to accomplish tasks.
Stakeholder	An enterprise, organization, or individual having an interest or a stake in the outcome of the engineering of a system.
System	A combination of two or more interrelated pieces of equipment (or sets) arranged in a functional package to perform an operational function or to satisfy a requirement.
Systems Architecture	The organizational structure of a system or component, their relationships, and the principles and guidelines governing their design and evolution over time.
Systems Engineering	An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem
System Function	An activity that the system must be designed to perform (Destroy targets) and an evaluation consideration for alternative system designs

Term	Definition
Validation	The process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation.
Verification	The process of determining that a model or simulation implementation accurately represents the developer’s conceptual description and specifications.

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